The Renewability of Grazingland Ecosystems

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Native rangeland and domesticated grassland ecosystems are the major grazingland renewable natural resources in the Northern Plains. The 'natural resources' portion of this term indicates that these are assets produced by processes of nature that can be sources of wealth. The 'renewable' portion of this term is usually not recognized as an extremely important description which declares that grazingland ecosystems have the capability to return to the potential production level of the good-as-new condition following deterioration of ecosystem performance that results from unenlightened management practices. Grazingland ecosystems degrade (decrease) when management causes output of essential elements to be greater than input. Conversely, grazingland ecosystems aggrade (increase) when management causes input of essential elements to be greater than output (McGill and Cole 1981).

The single most important factor that determines when a grazingland ecosystem is degraded or aggraded by a particular type of management practice depends on whether the biomass of soil microorganisms is decreasing or increasing. A large biomass of soil microbes is required to aggrade grazingland ecosystems (Coleman et al. 1983, Schimel, Coleman, and Horton 1985, Cheng and Johnson 1998). The soil microorganisms are the renewable portion of grazingland natural resources.

Grazingland ecosystems aggrade when beneficial management practices cause increased quantities of labile (readily available) simple carbon chain energy from grass tillers at vegetative growth stages to be exudated (released) through the roots into the rhizosphere providing the limiting nutrient necessary for microorganism biomass to increase (Anderson et al. 1981, Curl and Truelove 1986, Whipps 1990, Hamilton and Frank 2001, Manske 2011). The resulting increased biomass of soil microorganisms are able to decompose and mineralize components of the soil organic matter at stimulated rates producing greater quantities of essential elements in plant available mineral (inorganic) forms (Coleman et al. 1983, Klein et al. 1988, Bird et al. 2002, Burrows and Pfleger 2002,

Rillig et al. 2002, Driver et al. 2005). The increased quantities of available essential elements provide for increased production of plant herbage biomass. Greater quantities and improved quality of herbage provide for increased quantities of livestock weight production (Manske 2008).

These resulting increased quantities of microbe, plant, and animal biomass supplies greater amounts of residue to become soil organic matter. The quantity of organic matter in a soil can increase at annual increments until the steady state is reached where the inputs and the outputs are at equilibrium levels. The equilibrium level of soil organic matter is variable and affected by differences in soil texture, mean temperature, growing season precipitation, and type of management practice. Soil organic matter equilibrium level increases when the texture of the soils change from coarse textured sandy soils to finer textured silty and clayey soils; it increases as mean temperatures cool; and it increases as growing season precipitation increases (Weaver et al. 1935, Brady 1974, Parton et al. 1987). The equilibrium level of soil organic matter for any specific soil type in a region can be decreased or increased depending on whether the effects from the type of management practice implemented causes a decrease or an increase in the soil microorganism biomass (Dormaar et al. 1977, Campbell and Souster 1982, Naeth et al. 1991, McLaunchlan et al. 2006).

The quantity of soil organic matter in relation to the equilibrium level is a direct indication of soil primary productivity and is a sensitive measure of changes in soil quality and ecosystem functionality (Burke et al. 1989, Gregorich et al. 1994). Soil organic matter is the primary nutrient reservoir of grazingland ecosystems and contains the organic forms of the essential elements, carbon (C), hydrogen (H), nitrogen (N), oxygen (O), phosphorus (P), and sulfur (S); the ionic forms of the macronutrients, calcium (Ca), magnesium (Mg), and potassium (K); and the ionic forms of the micronutrients, boron (B), copper (Cu), molybdenum (Mo), and zinc (Zn) (Brady 1974, Van Veen and Paul 1981, Burke et al. 1989). Essential elements stored in the soil organic matter as unavailable organic forms or as ions

adsorbed by colloidal complexes are biologically and chemically immobilized, respectively, and these stable forms are not subjected to great potential losses through volatilization or leaching movement (Legg 1975, Gibson 2009). Availability of the immobilized essential elements is conducted through the ecosystem biogeochemical cycles performed by soil microorganisms (McGill and Cole 1981, Cheng and Johnson 1998, Manske 2012, 2014). The quantity of available essential elements is determined by the rates of soil organic matter decomposition and mineralization that are directly regulated by the biomass of active soil microorganisms and are not affected by the quantity or rate of residue accession (Van Veen and Paul 1981). Increases in the organic matter content of a soil improves the stability of soil aggregates, improves the physical and chemical properties, improves air and water infiltration and water holding capacity, improves soil fertility, and increases cation exchange capacity (Schimel, Coleman, and Horton 1985, Six et al. 1998, 2004).

This report will evaluate the renewability of grazingland ecosystems in silty soils of the mixed grass prairie that are managed by three types of long-term (32 years) management strategies by comparing differences in the quantities of soil organic matter (SOM), soil organic carbon (SOC), and soil organic nitrogen (SON), and to quantify differences in the soil microorganism rhizosphere volume, the mean monthly amounts of soil available mineral nitrogen, and the mean monthly amounts of transformed mineral nitrogen that result from the combined effects of each of the three different management strategies.

Procedure

Three management treatments were evaluated (1) the long-term nongrazed control was not grazed, mowed, or burned, (2) the 4.5-month seasonlong practice was grazed for 137 days from early June to mid October on one pasture stocked at 2.86 acres per cow-calf pair per month, and (3) the 4.5-month twice-over rotation system was grazed for 137 days from early June to mid October on three rotated pastures stocked at 2.20 acres per cow-calf pair per month. Each of the three management treatments had two replications. The land included in this study had received the same previous management of seasonlong grazing for more than 30 years before the initiation of the research treatments in 1983.

Soil weight of silty soil in southwestern North Dakota was determined from average silty soil bulk density from analysis of comparable soils (Anonymous circa early 1980's) at incremental depths of 0-6, 6-12, 12-24, 24-36, and 36-48 inches. Weight of soil organic matter (SOM) was determined from the soil weight of silty soil and percent soil organic matter from analysis conducted by the North Dakota State University Soil Testing Laboratory of soil core samples from four replicated cores on silty ecological sites of each management treatment at incremental depths of 0-6, 6-12, 12-24, 24-36, and 36-48 inches collected during June of 2013 and 2014. Weight of soil organic carbon (SOC) was determined from the soil weight of silty soil and percent soil organic matter multiplied by 0.58 (58% organic carbon content of soil organic matter) (Anonymous nd, NRCS Staff 2009, Pluske et al. 2015) of soil core samples on silty ecological sites of each management treatment at incremental depths of 0-6, 6-12, 12-24, 24-36, and 36-48 inches. Weight of soil organic nitrogen (SON) was determined from the soil weight of silty soil and percent soil organic matter multiplied by 0.058 (estimated 5.8% organic nitrogen content of soil organic matter) of soil core samples on silty ecological sites of each management treatment at incremental depths of 0-6, 6-12, 12-24, 24-36, and 36-48 inches. Data were reported as mean of two years.

Rhizosphere volume associated with grass roots was determined from two replicated intact soil cores from silty ecological sites on each of the study treatments collected monthly (June to September) during 2002, year 20. Plastic PVC pipe 3 inches (7.62 cm) in diameter and 4 inches (10.16 cm) long was forced into sample site soil. Intact soil-plant cores and pipe were excavated and transported to the laboratory. The soil matrix of collected soil cores was carefully removed from between the rhizospheres. The exposed rhizospheres were sprayed with a clear acrylic coating to prevent damage during further handling. The length and diameter of the rhizosphere around each root of every plant were measured in inches with a vernier caliper, then converted to metric system values. The length and diameter measurements were used to determine the volume of each rhizosphere (Gorder, Manske, and Stroh 2004. Data were analyzed and reported as a mean of the two replications per sample period during August and September.

Soil mineral nitrogen, nitrate (NO_3) and ammonium (NH_4), was determined from four replicated soil core samples collected at silty ecological sites inside protective exclosures for the nongrazed treatment, and outside exclosures exposed to selected treatments for the seasonlong and twice-over rotation grazing management systems with the 1

inch Veihmeyer soil tube at incremental depths of 0-6, 6-12, 12-24 inches on monthly periods during May to October of 2013 and 2014. Analysis of soil core samples for available mineral nitrogen (NO_3 and NH_4) was conducted by the North Dakota State University Soil Testing Laboratory. Two year mean available mineral nitrogen was reported as pounds per acre.

Transformation (immobilization) of nitrate (NO_3) and of ammonium (NH_4) was determined by the net mineralization measurement of the nitrogen balance equation of a soil-plant system (Bloem et al. 2006). The quantity of mineral nitrogen in a soil is the net difference between the total quantity of organic nitrogen mineralized by soil microorganisms and the quantity of mineral nitrogen immobilized by plants and soil microbes (Brady 1974, Legg 1975). The general nitrogen balance equation is simply: the quantity of nitrogen at time 2 minus the quantity of nitrogen at time 1, the difference is the quantity of the transformed nitrogen. Nitrogen quantity at time 1 is the May values. Nitrogen quantity at time 2 is the values at each successive month. Transformed nitrogen is the quantity of uptake by plants and soil microbes and converted into organic nitrogen plus the quantity of nitrogen loss by leaching or volatilization. Loss by leaching on Northern Plains prairies is negligible (Power 1970, Brady 1974, Wight and Black 1979, Coyne et al. 1995). Loss by volatilization during 2013 and 2014 with high soil water content would also be negligible. Transformation of ammonium (NH_4) could include some conversion to nitrate (NO_3). Most of the transformed nitrogen would be the quantity converted into organic nitrogen by plants and soil microbes.

Results

The quantities of soil organic matter (SOM), soil organic carbon (SOC), and soil organic nitrogen (SON) on the silty ecological sites should have been the same on all three management treatments at the start of this study in 1983. Differences in the quantities of these soil organic parameters after 32 years of uninterrupted application of each of the three treatments would be caused by the combined effects that each management strategy had on the soil microorganism biomass and the ecosystem biogeochemical processes and the resulting simultaneous affects on the soil quality and ecosystem productivity.

The quantity of soil organic matter (SOM) to the 48 inch soil depth on the nongrazed treatment was 106.7 tons/ac. The quantity of SOM on the

seasonlong treatment was 91.1% greater than that on the nongrazed treatment. The quantity of SOM on the twice-over treatment was 117.0% greater than that on the nongrazed treatment. The twice-over treatment had accumulated a 54.1% greater quantity of SOM than had been accumulated on the seasonlong treatment (figure 1).

The quantity of soil organic carbon (SOC) to the 48 inch soil depth on the nongrazed treatment was 62.0 tons/ac. The quantity of SOC on the seasonlong treatment was 56.2 tons/ac greater than that on the nongrazed treatment. In 32 years, the seasonlong treatment had accumulated 1.8 tons/ac/yr of SOC more than the annual amount that accumulated on the nongrazed treatment. The quantity of SOC on the twice-over treatment was 72.1 tons/ac greater than that on the nongrazed treatment. In 32 years, the twice-over treatment had accumulated 2.3 tons/ac/yr of SOC more than the annual amount that accumulated on the nongrazed treatment. The twice-over treatment had accumulated 0.5 tons/ac/yr of SOC more than the annual amount that accumulated on the seasonlong treatment (figure 2).

The quantity of soil organic nitrogen (SON) to the 48 inch soil depth on the nongrazed treatment was 12,407.4 lbs/ac. The quantity of SON on the seasonlong treatment was 11,234.6 lbs/ac greater than that on the nongrazed treatment. In 32 years, the seasonlong treatment had accumulated 351.1 lbs/ac/yr of SON more than the annual amount that accumulated on the nongrazed treatment. The quantity of SON on the twice-over treatment was 14,418.2 lbs/ac greater than that on the nongrazed treatment. In 32 years, the twice-over treatment had accumulated 450.6 lbs/ac/yr of SON more than the annual amount that accumulated on the nongrazed treatment. The twice-over treatment had accumulated 99.5 lbs/ac/yr of SON more than the annual amount that accumulated on the seasonlong treatment (figure 3).

The soil microorganism biomass cannot be easily measured in pounds per acre. The volume of the rhizosphere cylinders around active perennial grass roots were painstakingly measured on the three management treatments during the growing season of 2002, study year 20. The volume of the rhizosphere is directly proportional to the activity and biomass of the microorganisms (Manske 2011). The rhizosphere volume on the nongrazed treatment during August and September was 2,415.2 cm^3/m^3. The rhizosphere volume on the seasonlong treatment was 532.2 cm^3/m^3 smaller than, but not significantly different ($P < 0.05$) from, the volume on the nongrazed treatment,

for a reduction of 22%. The rhizosphere volume on the twice-over treatment was 4,469.5 cm^3/m^3 larger than, and significantly greater (P < 0.05) than, the volume on the nongrazed treatment. The rhizosphere volume on the twice-over treatment was 5,001.7 cm^3/m^3 larger than, and significantly greater (P < 0.05) than, the volume on the seasonlong treatment. The rhizosphere volume on the twice-over treatment was 185.1% greater than that on the nongrazed treatment and was 265.6% greater than that on the seasonlong treatment (figure 4).

Available soil mineral nitrogen is the major limiting factor of herbage growth on grazingland ecosystems (Wight and Black 1979). A minimum quantity of mineralization of soil organic matter that supplies 100 pounds of mineral nitrogen per acre is required to sustain herbage production at biological potential levels on grazinglands of the Northern Plains (Wight and Black 1972).

The quantity of available soil mineral nitrogen (NO_3 + NH_4) to the 24 inch soil depth on the nongrazed treatment was 58.4 lbs/ac, 41.6% lower than the minimum quantity required. The quantity of available soil mineral nitrogen on the seasonlong treatment was 47.1% greater than that on the nongrazed treatment and 14.1% lower than the minimum quantity required. The quantity of available soil mineral nitrogen on the twice-over treatment was 75.7% greater than that on the nongrazed treatment, was 19.4% greater than that on the seasonlong treatment, and was 2.6% greater than the minimum quantity required (figure 5).

The quantity of available soil mineral nitrogen (NO_3 + NH_4) varies with changes in soil microorganism biomass and plant phenological growth and development during the growing season (Whitman 1975) and is the net difference between the total quantity of soil organic nitrogen (SON) mineralized by soil microorganisms and the quantity of mineral nitrogen immobilized (transformed) by plants and soil microbes (Brady 1974, Legg 1975). Greater quantities of soil mineral nitrogen transformed indicates greater productivity on the grazingland ecosystem. The quantity of soil mineral nitrogen (NO_3 + NH_4) to the 24 inch soil depth that was transformed (immobilized) on the nongrazed treatment was 10.1 lbs/ac during a mean growing season month. The quantity of soil mineral nitrogen transformed on the seasonlong treatment was 155.4 % greater than that on the nongrazed treatment. The quantity of soil mineral nitrogen transformed on the twice-over treatment was 277.2% greater than that on

the nongrazed treatment and was 48.0% greater than that on the seasonlong treatment (figure 5).

Discussion

The threshold quantity of a minimum of 100 pounds of mineral nitrogen per acre is required to sustain herbage production at biological potential levels in grazingland ecosystems (Wight and Black 1972, 1979) was the prerequisite standard value necessary to define the proper perspective from which to evaluate these data sets.

The soil microorganism biomass and biological activity on the ecosystems managed with the nongrazed and seasonlong treatments were not large enough to mineralize the minimum threshold quantity of mineral nitrogen. Grazingland ecosystems managed by traditional concepts are not renewable to the good-as-new condition and continue to slowly degrade at various rates because traditional concepts manage for the "use" of only the primary ecosystem components that produce short-term capture of wealth. Traditional concepts do not place importance on the functionality of ecosystem biogeochemical processes. The grazingland ecosystems managed with the nongrazed and seasonlong treatments were degrading at different rates as a result of inferior microorganism biomass and deficient performance of the biogeochemical processes causing reduced quantities of available essential elements and reduced ecosystem productivity.

The nongrazed treatment is not grazed by livestock and quantities of simple carbohydrates greater than the typical low leakage rate are not exuded into the rhizosphere. The nongrazed treatment removed grazing defoliation by livestock for the purpose of resting the grazingland ecosystems as a restoration management practice developed from traditional concepts that do not go deeper than the soil surface. This misguided practice was based on a naive assumption that the observed vigor depletion was caused by livestock grazing, rather than by poor management of livestock grazing, and that the lost vigor could be restored by resting. Ironically, removal of livestock grazing does not rest an ecosystem and enhance the soil microorganism biomass and does not invigorate the degrading ecosystem. The biomass of soil microorganisms on a nongrazed ecosystem can fluctuate with the soil moisture levels but cannot increase above the mass that can be supported by the small quantities of available energy provided in the normal carbohydrate leakage rate and the small amount of short carbon

chains and water soluble crude protein remaining within the recently dead plant residue. As a result, the microorganism biomass on the nongrazed ecosystems remains small. Grazingland ecosystems managed by the nongrazed treatment are not renewable.

The seasonlong treatment was managed by traditional concepts that consider the aboveground plants, the livestock, and sometimes wildlife habitat; unfortunately, the importance of the soil microorganism biomass is not even acknowledged. The grazing periods on the seasonlong treatment are not coordinated with grass tiller phenological growth stages and partial defoliation by the grazing livestock does not cause large quantities of simple carbohydrates to be exudated, but does cause quantities greater than typical leakage rates to be exudated into the rhizosphere. Any enhancement of biological activity below the soil surface is purely unintentional. When characteristic seasonlong stocking rates cause quantities greater than 50% of the leaf weight to be removed from grass tillers at vegetative growth stages, the remaining leaf area is insufficient to photosynthesize adequate quantities of carbohydrates to meet the demand for average growth. Without large quantities of exudated simple carbohydrates, the microorganism biomass on seasonlong managed ecosystems remains mediocre. Grazingland ecosystems managed by the seasonlong treatment are not renewable.

The soil microorganism biomass and biological activity on the grazingland ecosystems managed with the twice-over rotation strategy were great enough to mineralize more than 100 pounds of mineral nitrogen per acre. Most of the soil microorganisms that occupy intact soils inhabit the narrow zone around active perennial plant roots; the rhizosphere. Soil microorganism populations existing in the rhizosphere are limited in production by access to energy from simple carbon chains. The grazing periods on the twice-over rotation system are coordinated with the grass tiller phenological growth and development. Partial defoliation by grazing livestock that removes 25% to 33% of the aboveground leaf weight on about 60% to 80% of the grass tillers at vegetative growth stages between the three and a half new leaf stage and the flower stage intentionally causes large quantities of grass leaf photosynthesized simple carbohydrates to be exudated through the roots into the rhizosphere. This great increase in availability of simple carbon compounds in the ecosystems managed with the twice-over rotation system elevate microbe activity

and are responsible for the large expansion in the microorganism biomass.

The grazingland ecosystems managed with the twice-over rotation strategy were aggrading and were progressing well along the ecosystem renewal processes towards the good-as-new condition. The rhizosphere volume and, accordingly, the soil microorganism biomass on the twice-over managed ecosystems were enormous and were able to perform the biogeochemical processes at elevated rates greatly increasing the annual accumulation of soil organic matter and annually capturing much greater quantities of essential elements than the amount removed from the ecosystem. The input accumulation of essential elements were greater than the output quantities showing that grazingland ecosystems possibly do not or cannot function exactly according to the steady state at equilibrium levels. The large biomass of microorganisms were able to decompose and mineralize components of the soil organic matter at rapid rates providing great quantities of available essential elements including mineral nitrogen and the macronutrients and micronutrients. The transformation of these large quantities of essential elements back to their organic forms greatly increased ecosystem productivity. The renewal processes on the grazingland ecosystems managed with the twice-over rotation strategy were superior to the biological activity on the ecosystems managed by the seasonlong and nongrazed treatments.

Grazingland ecosystems managed with the twice-over rotation strategy are renewable. These complex ecosystems consist of biotic (living) and abiotic (nonliving) components. The biotic components are the grass plants, soil microorganisms, and grazing livestock that have biological and physiological requirements and have developed complex symbiotic relationships. The abiotic components include radiant energy from sunlight, the major essential elements of carbon, hydrogen, nitrogen, and oxygen with separate but closely linked biogeochemical cycles that transform the elements between organic forms and inorganic forms, and the minor essential elements of the macronutrients and micronutrients. Renewal of grazingland ecosystems requires numerous biogeochemical processes performed by a large biomass of soil microorganisms. A large biomass of active soil microorganisms require large quantities of grass plant produced energy from simple carbon chains. Movement of large quantities of short carbon chain energy from vegetative grass tillers to the soil microorganisms in the rhizosphere requires partial defoliation by grazing livestock

coordinated with grass tiller phenological growth stages as accomplished on grazingland ecosystems managed with the twice-over rotation strategy. The cryptobiotic soil microorganisms are vital to the functionality and productivity of grazingland ecosystems; and a large biomass of soil microorganisms are necessary for grazingland ecosystem renewability to the good-as-new condition.
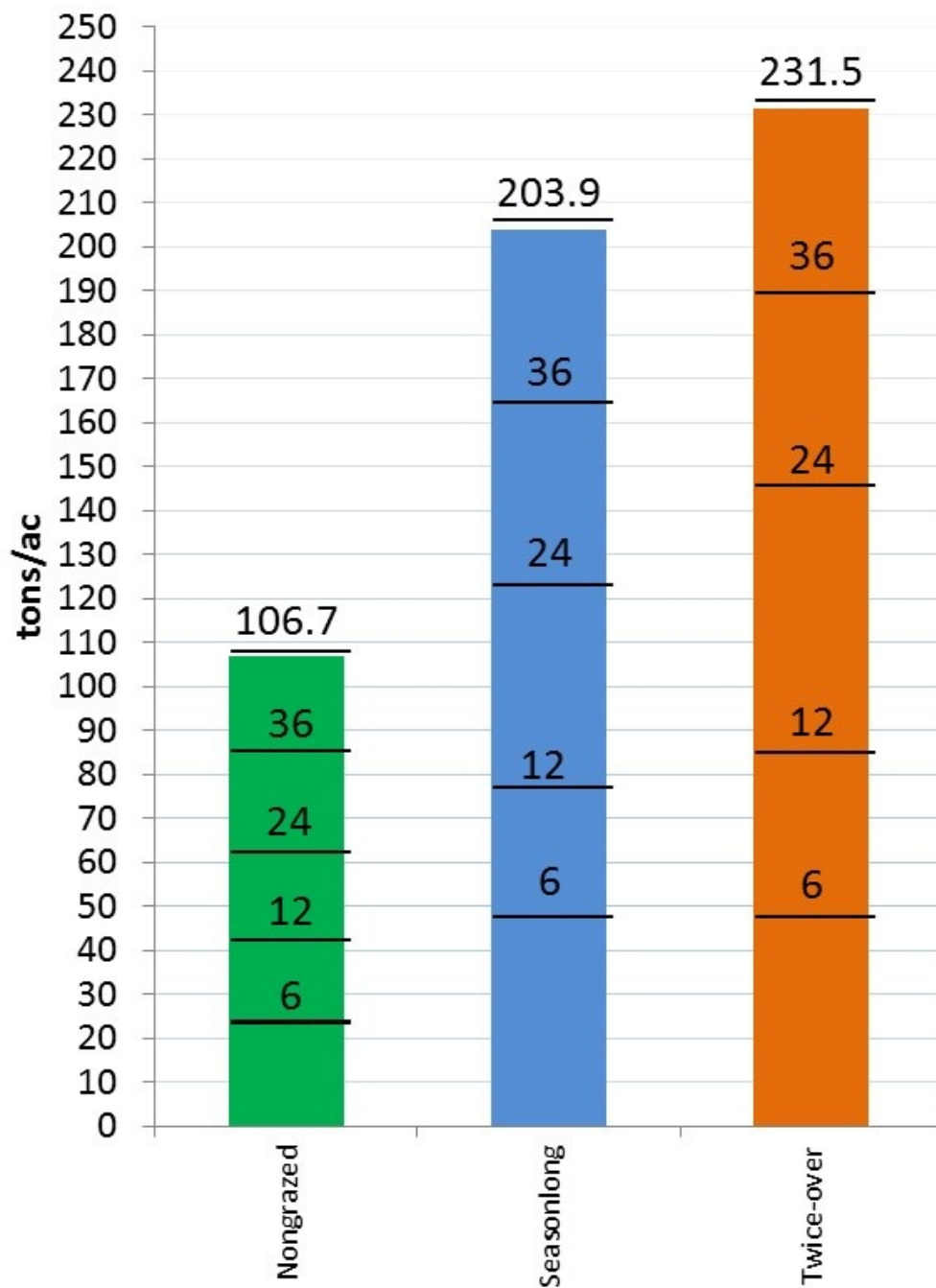
Figure 1. Soil Organic Matter (SOM) in tons/ac at 5 incremental depths to 48 inches on Nongrazed, Seasonlong, and Twice-over rotation management strategies after 32 years.
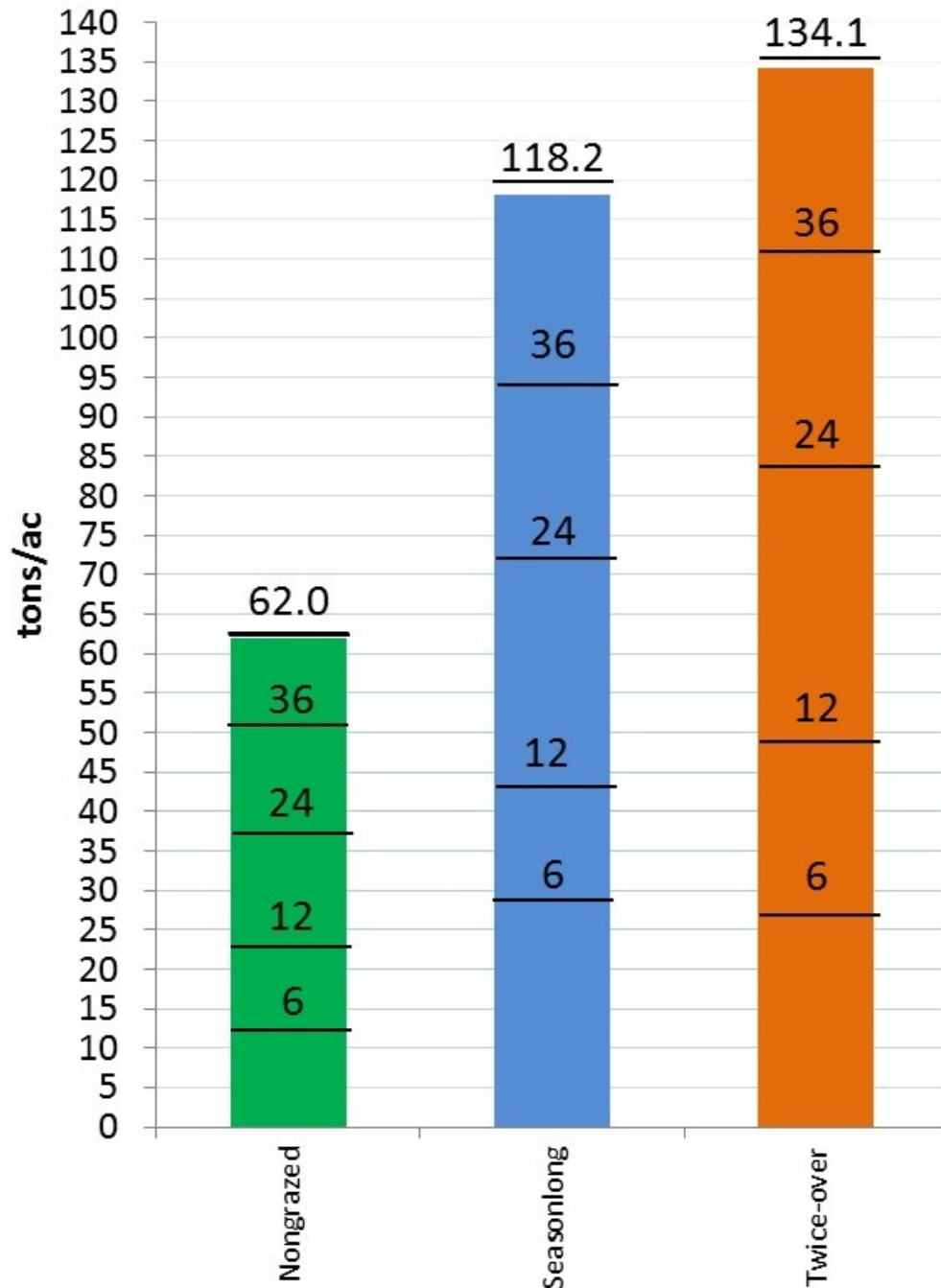
Figure 2. Soil Organic Carbon (SOC) in tons/ac at 5 incremental depths to 48 inches on Nongrazed, Seasonlong, and Twice-over rotation management strategies after 32 years.
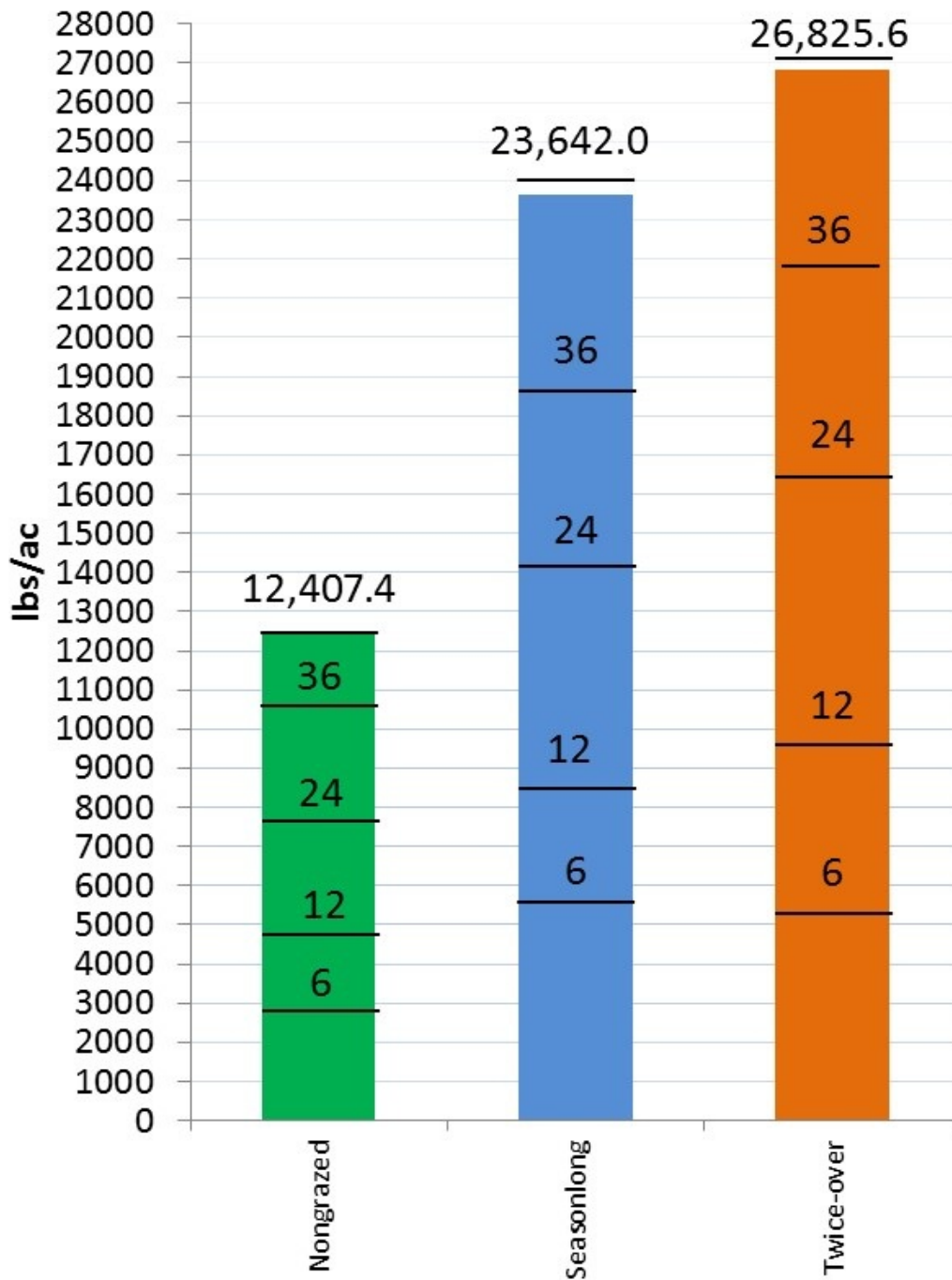
Figure 3. Soil Organic Nitrogen (SON) in lbs/ac at 5 incremental
depths to 48 inches on Nongrazed, Seasonlong, and
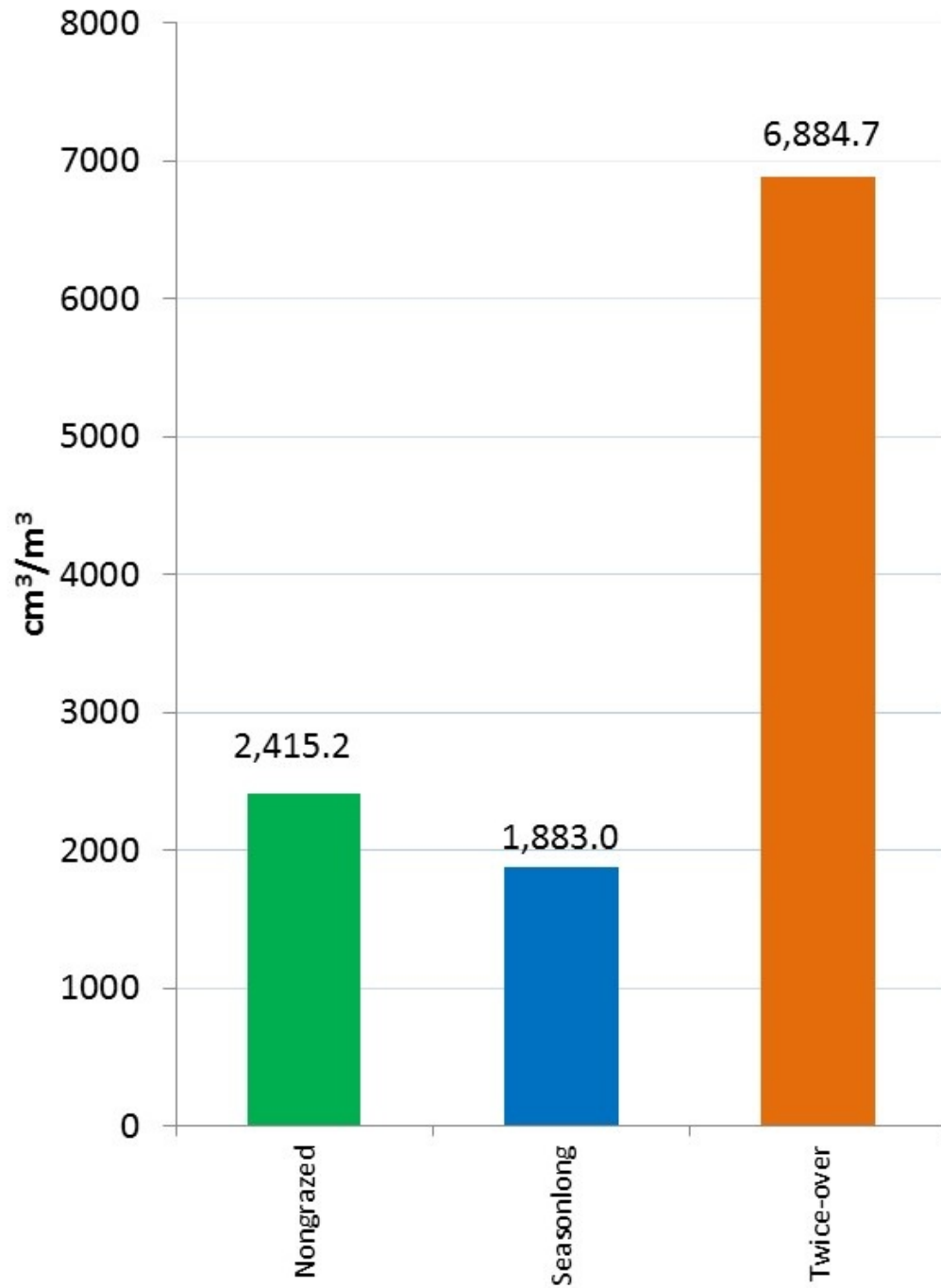Twice-over rotation management strategies after 32 years.

Figure 4. Rhizosphere Volume in cm^3/m^3 during August and September on Nongrazed, Seasonlong, and Twice-over rotation management strategies, 2002.
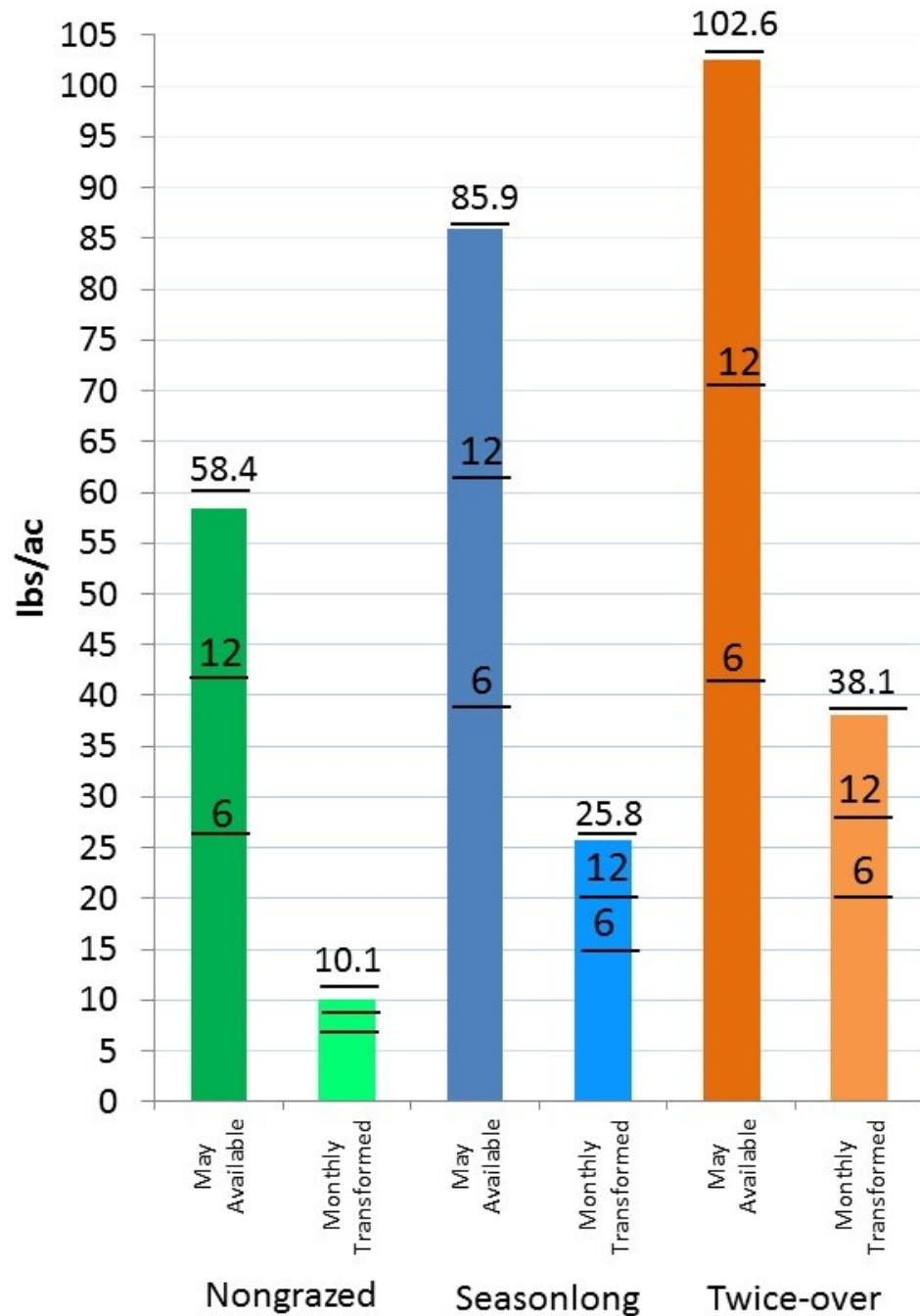
Figure 5. Mineral Nitrogen ($NO_3 + NH_4$) monthly available and transformed in lbs/ac at 3 incremental depths to 24 inches on Nongrazed, Seasonlong, and Twice-over rotation management strategies, 2013-2014.

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