Biogeochemical Model to Improve Soil Quality

Llewellyn L. Manske PhD
Research Professor of Range Science
North Dakota State University
Dickinson Research Extension Center
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Soil quality and soil production capacity of the worlds renewable natural resources, which are the rangelands, grasslands, and croplands, have severely decreased as a result of diminished ecological processes (Bloem et al. 2006).

These renewable natural resources are no longer able to maintain current production at potential levels as a result of the management caused deterioration of the ecosystem processes. The primary reason for this decline in resource productivity is that management of renewable natural resources has traditionally been conducted from the perspective of the "use" of the resource. The value of a resource has been determined by the quantity of product removed. This shortsighted management has not considered renewable resources as complete functioning ecosystems and consequently has diminished the biogeochemical processes, decreased the soil microorganism biomass, and caused the loss or removal of greater quantities of essential elements than the amount replaced annually (Manske 2008).

Soils with low quality generally have low organic matter content, low quantities of essential elements, low microorganism biomass, low biogeochemical activity, low aggregation and poor structure, reduced pore spaces, low aeration, and low water infiltration (Manske 2012b).

The primary stages for restoration of low quality soils requires improvement of the biogeochemical processes, increases of the soil microorganisms biomass, and replacement of lost or removed essential elements. Vital improvement in soil quality of renewable resources has been impeded because of the unavailability of a thorough description of the ecological processes in high quality soils (Manske 2013b).

A description of the ecological processes in managed high quality cropland soils has not yet been produced (Bloem et al. 2006). However, the biogeochemical processes of biologically managed high quality prairie soils have been described (Manske 2013b). Rangeland, grassland, and most cropland soils were transformed from prairie soils. The biogeochemical processes in renewable resources soils should be analogous to the biogeochemical processes in prairie soils. The described ecological processes in prairie soils can realistically provide a functional prototype from which to use as procedural guidelines for soil quality improvement of the other renewable natural resources (Manske 2013b).

Management that will improve soil quality must consider renewable natural resources as complex ecosystems consisting of numerous interactive biotic (living) and abiotic (nonliving) components. The biotic components are the plants, soil microorganisms, and large organisms (insects, wildlife, and livestock) that have biological and physiological requirements. The abiotic components include the major and minor essential elements that have transformable characteristics between organic and inorganic forms through biogeochemical processes, and also includes the abiotic radiant energy from the sun. Soil ecosystems are functioning units of coacting biotic organisms interacting with the abiotic components and the environmental conditions. If any of the numerous interactive biogeochemical processes are not functioning at potential level, the ecosystem does not produce at potential level (Manske 2012a).

Renewable natural resource ecosystems are open systems with biological, geological, chemical, and atmospheric pathways that transfer the major essential elements into and out of the ecosystem. The major essential elements are carbon, hydrogen, nitrogen, and oxygen and they have separate but closely linked biogeochemical cycles that transform the elements between organic and inorganic forms. Light is radiant energy from the sun, it is necessary for photosynthesis, and it is the initial source of energy for all trophic levels in the food web of an ecosystem (Manske 2013a).

The minor essential elements consist of seven macrominerals and ten microminerals that are required by most living organisms (Manske 2001). The minor elements have biogeochemical cycles or parts of cycles that transform the elements between organic and inorganic forms while they are within an ecosystem. There are numerous pathways that transfer minor essential elements out of an ecosystem. However, there are no readily available natural pathways that can transfer minor essential elements into an ecosystem. After a macromineral or a micromineral has been completely depleted from a renewable natural resource ecosystem, that soil is deficient of that minor essential element.

Renewable resource ecosystems that have greater output than input of essential elements are deteriorating and are not sustainable. Ecosystems that are managed to have greater natural input than output of essential elements have high quality soil and are sustainable (Manske 2012a).

The working model that improves soil quality of a renewable natural resource ecosystem follows the management of a grazed grassland. The management strategies must meet the biological and physiological requirements of the biotic components, stimulate the biogeochemical processes that cycle the abiotic components to function at potential capacity, and replenish the essential elements through ecosystem processes at the same or greater quantities at which the elements were lost or removed from the ecosystem (Manske 2008).

Perennial grass plants on a grazed grassland produce twice the leaf biomass needed to synthesize the compounds used in growth and physiological processes. About 67% of the annual perennial grass biomass is produced belowground and about 33% is produced aboveground. About 50% of the aboveground biomass is expendable by the plant. About 50% of the expendable leaf material is removed as senescent leaves that are broken from the plant and fall to the ground, or as leaf material consumed by insects and wildlife. About 50% of the expendable leaf material, or 25% of the aboveground biomass, is consumed by grazing livestock (Manske 2012a).

Perennial grass leaf material consists of digestible nutrients and nondigestible structural components. All of the nondigestible dry matter consumed by grazing livestock is deposited on the ground as manure in a couple of days. Most of the nutrients consumed and used by livestock for maintenance are returned to the ecosystem in the feces and urine. About 15% of the nutrients contained in the consumed leaf material is extracted by stocker heifers and steers and retained for growth. About 30% of the nutrients contained in the consumed leaf material is extracted by lactating cows, with a portion retained by the cow for production, and the remainder of the extracted nutrients passed to her calf for growth (Russelle 1992, Gibson 2009).

None of the aboveground and belowground dry matter biomass produced during the growing season is removed by livestock from the grazingland ecosystem. All of the essential elements contained in the belowground biomass stay in the ecosystem. Livestock consume about 25% of the aboveground biomass. About 75% of the essential elements contained in the nonconsumed aboveground biomass stay in the ecosystem. About 85% of the essential elements consumed by livestock are returned to the ecosystem in the feces and urine. Nearly all of the essential elements used in the annual production of plant herbage biomass, soil organism biomass, insect biomass, wildlife biomass, and livestock biomass are retained and recycled within the ecosystem (Manske 2013a).

The small quantity of major essential elements that are lost or removed annually from a renewable natural resource ecosystem can be replenished at equal or greater amounts by capturing input major essential elements from the surrounding environment through ecosystem processes associated with active plants or soil microorganisms (Manske 2013a).

Atmospheric carbon dioxide is the ecosystem input source for carbon. The carbon dioxide is fixed with hydrogen from soil water during the plant process of photosynthesis which converts energy from sunlight into chemical energy and assimilates simple carbohydrates (Manske 2013c).

Soil water is infiltrated precipitation water and is the ecosystem input source for hydrogen. Soil water is absorbed through the roots and distributed throughout the plant within the xylem vascular tissue (Manske 2013c).

Wet deposition of nitrogen oxides following lightning discharge is the ecosystem input source for nitrogen at an average rate of 5 to 6 pounds per acre per year. The source of nitrogen for plant growth is the mineral nitrogen converted from soil organic nitrogen by soil microorganisms (Manske 2013c). The greater the soil microorganism biomass, the greater the quantity of available soil mineral nitrogen.

Atmospheric and soil elemental oxides are the ecosystem input sources for oxygen. The oxygen biogeochemical cycle is closely linked to the carbon cycle and the water cycle (Manske 2013c).

Radiant light from the sun is the ecosystem input source for energy (Manske 2013c). Solar energy is the only energy source that powers biogeochemical processes in renewable natural resource ecosystems.

Energy flow within an ecosystem includes three biogeochemical cycles, the carbon, hydrogen, and oxygen cycles. Photosynthesis is the process that captures energy. Respiration is the process that releases energy (Manske 2013a).

Nitrogen flow within an ecosystem includes four biogeochemical cycles, the nitrogen, oxygen, carbon, and hydrogen cycles. Immobilization is the process that changes nitrogen from inorganic forms to organic forms, primarily nucleic acids and proteins. Mineralization is the process that changes nitrogen from organic forms to inorganic forms, primarily mineral nitrogen as nitrate and ammonium. A great soil microorganism biomass is required for adequate nitrogen flow in renewable natural resource ecosystems (Manske 2013a).

Decomposition of organic matter within an ecosystem includes all of the biogeochemical cycles. Decomposition is the process that changes complex organic matter into compounds and then into the essential elemental forms by soil microorganisms. The large soil microorganism biomass required for decomposition of an ecosystems organic matter cannot extract adequate quantities of energy from the organic matter and must be supplied with additional short chain carbon energy from living plants (Manske 2013a).

Renewable natural resource ecosystems that have improved soil quality and are functioning at or near potential capacity retain or recapture all of the essential elements used for biomass production during a growing season. About 4 to 5 times the quantity of essential elements contained in living organisms are held as immobilized organic compounds in the soil which prevents potential losses. Essential elements stored in the soil in the inorganic form are highly vulnerable to being lost through leaching, volatilization, and oxidation. A portion of the immobilized essential elements are mineralized by the soil microorganisms and made available to plants and other soil organisms that synthesize vital organic compounds of carbohydrates, proteins, and nucleic acids which are then used for additional growth (Manske 2012a).

The quantity of available essential elements in an ecosystem is dependent on the rate of mineralization of the soil organic matter by soil microorganisms. The larger the microorganism biomass, the greater the quantity of mineralized organic matter. Soil microorganisms are limited by access to simple carbohydrate energy. An increase in energy from short chain carbon compounds exudated from living plants, increases the biomass and activity of the soil microorganisms. Increased activity of soil microorganisms causes greater rates of mineralization that convert greater quantities of available inorganic essential elements resulting in greater quantities of ecosystem biomass production (Manske 2012a).

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