Improvement of Cropland Soil Quality Through Restoration of Ecosystem Biogeochemical Processes

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Report DREC 12-3059

Soil, the pedosphere, is the weathered surface layer of the earth's crust. The pedosphere, together with the atmosphere and the hydrosphere, make up the biosphere, which is the domain of living organisms. The pedosphere supports and sustains higher plants, upon which, animals and humans depend. Soil is generally about 50% solid and 50% pore spaces, and consists of abiotic components comprised of around 45% mineral matter, 3-5% organic matter, 20-30% water, and 20-30% air, and of biotic components comprised of plant roots and microorganisms (Odum 1971, Brady 1974).

Soil production capacity in cultivated land has decreased worldwide since the early 1980's (Bloem et al. 2006). This widespread problem has become a major international concern. Following the United Nations Conference on Environment and Development, and the adoption of the Treaty on Biological Diversity of Rio de Janeiro in 1992, most of the participating countries established scientific programs to determine the problems causing declining cropland productivity, to identify assessment criteria for soil quality, and to evaluate land management practices that sustain soil quality. The central focus term "soil quality" is a complex concept not easily defined and assessed except through use of the physical, chemical, and biological characteristics of soil as indirect indicators (Bloem et al. 2006).

The acknowledged best definition to date that represents the soil quality concept was published by the Soil Science Society of America (SSSA) (1994): 'Soil quality is the capacity of the soil to function within ecosystem boundaries, to sustain biological productivity, to maintain environmental quality, and to promote plant and animal health'. Where "ecosystem boundaries" is the recognition that each soil is different; "productivity" is the soils capacity to increase plant biological production; "environmental quality" is the soils capacity to attenuate environmental contamination, pathogens, and external damage; and "health of living organisms" is the interrelation between soil quality and animal, plant, and human health (Bloem et al. 2006).

Soil quality depends on several physical, chemical, and biological properties. However, during assessment of soil quality, the biological parameters have greater importance because organisms respond more rapidly than most chemical and physical parameters to changes in land use, environmental condition, or contamination. The soil organisms play crucial roles in many processes that sustain soil quality, such as organic matter decomposition, nutrient cycling, and aggregate formation and stabilization of structure. Numerous European reports have suggested that all soil quality assessments should include three basic measurements: 1) Soil Microbial Biomass, 2) Basal Soil Respiration by Aerobic Carbon Mineralization, and 3) Soil Potential Nitrogen Mineralization (Bloem et al. 2006).

Soil microorganisms are cryptobiota; hidden soil life, or creatures not visible with the naked eye; and are thus not bestowed with credit equal to their biological importance. Not only are they difficult to see, they are difficult to study. Less than 1% of the microbes in intact soils and less than 10% of the microbes in arable soils have been grown on culture colonies. One gram (0.035 oz) of healthy soil is the habitat for more than 1,000,000,000 (1 billion) bacteria, belonging to about 10,000 to 100,000 different microbial species (Bloem et al. 2006). Soil microorganisms cycle essential elements and are the primary reason the ecosystems of the world's renewable natural resources are functionally renewable.

Most of the cropland soils in the Northern Plains have had a long history of traditional tillage management. Tillage of cropland soils kills weeds, mixes previous years residue, and mellows hard soil. However, mechanical manipulation of soil also increases compaction, increases bulk density, decreases aggregation and structure, reduces pore spaces, reduces aeration, decreases water infiltration, and exposes soil to wind and water erosion. Mechanical tillage of a soil greatly increases oxidation of soil organic matter content and increases the release of carbon dioxide. During the harvest period, cropland soils lose a high proportion of the essential elements with the annual removal of most of the aboveground plant material as grain and straw for human or animal food causing rapid decreases in the soil organic matter and nitrogen content (Brady 1974).

Cropland fertility management meets the nutrient needs of the crop to be grown through a combination of the current evaluated soil test level of the inorganic nutrients available in the soil and the addition of chemical fertilizer containing nitrogen, phosphorus, and potassium at sufficient quantities that the total nutrients match the recommended regional yield potentials. This method does not give nutrient credits to the previous crop unless that crop was a legume and no credit is given to residue nutrients in the organic form (Franzen 2007). The unused nutrients remaining after the crop has matured are stored in cropland soils primarily in the inorganic form, which are highly vulnerable to being lost through leaching, volatilization, and oxidation. Cropland soils have low available essential nutrients in the inorganic form and require great inputs of manufactured essential nutrients. The practice of adding large amounts of fertilizer annually is nearly universally accepted as the way things need to be done as long as the input costs are less than the value of the produced commodity.

During recent years, a trend to reduce tillage and to leave greater amounts of crop residue on the cropland has developed with the expectation of improving soil quality. However, no cropping system has eliminated all tillage, and the current methodology to determine the quantities of straw residue that must remain on the land is the Revised Universal Soil Loss Equation that estimates straw quantities needed to keep water and wind erosion below the tolerable soil loss level. A national assessment of the amounts of residue needed to maintain soil organic matter is not available. The amounts of residue needed to maintain soil moisture, microbial activity, and long-term productivity have not been systematically evaluated (Walsh 2008).

Cropland soils of the Northern Plains have numerous problems. Cropland soils generally have low organic matter content, low microorganism biomass, low biogeochemical activity, low aggregation and structure, low pore spaces, low aeration, and low water infiltration. These problems indicate that cropland soils have low soil quality and low productivity without great nutrient inputs, and are in desperate need of restoration of the ecosystem biogeochemical processes.

Cropland soils of the Northen Plains developed from the soils of mixed grass prairie. The biogeochemical processes and activation of these processes in cropland soils should be analogous to the biogeochemical processes and activation of the processes in mixed grass prairie soils (Manske 2012b).

Croplands are a renewable natural resource with low soil quality and greatly reduced productivity. Croplands are not the only renewable natural resource with reduced productivity. The other renewable natural resources of grasslands, rangelands, forestlands, and fisheries also have reduced productivity. Worldwide, the small cities and towns that depend on farming, grazing, logging, and fishing for their economic base are declining in a symptomatic response to the decrease in resource productivity. The world's renewable natural resources are no longer able to maintain current production at potential levels as a result of the management caused deterioration of ecosystem biogeochemical 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. Management of renewable resources for the use narrowly considers only a few factors directly related to that use or the product removed. Management for the use neglects to consider renewable natural resources as ecosystems consisting of numerous components. Renewable natural resources are complex ecosystems consisting of numerous biotic components with individual biological requirements and numerous abiotic components that have changeable characteristics. Management of renewable resources must be focused towards meeting the requirements of all biotic and abiotic components of the ecosystem for the purpose of improving ecosystem biogeochemical processes and maintaining production at potential sustainable levels (Manske 2008).

Restoration of cropland ecosystem biogeochemical processes will require increasing the organic matter content, and increasing the soil microorganism biomass. Management practices that sustain large soil microbial populations and that activate ecosystem biogeochemical processes at levels that support crop production at regional yield potentials will need to be developed through research. Full restoration of cropland ecosystem soils will also require major paradigm shifts among soil scientists and crop producers.

In order to increase soil organic matter content on cropland ecosystems, the weight of the grain and straw removed at harvest will need to be replaced with an equal weight and quality of organic matter, preferably during the same year. Replacement of the removed essential elements with manufactured inorganic essential nutrients impede the performance of ecosystem biogeochemical processes.

In healthy grazingland ecosystems, all of the herbage biomass dry matter produced during a growing season and nearly all of the essential elements used in the annual production of herbage biomass and soil organism biomass are retained and recycled. Grazing livestock retain only about 15% of the nutrients contained in ingested forage for growth (Russelle 1992, Gibson 2009). All of the dry matter and most of the nutrients consumed by grazing livestock are returned to the ecosystem in the feces and urine. The small portion of the grazingland ecosystem essential elements of carbon, hydrogen, nitrogen, and oxygen removed or lost because of the livestock can be replenished annually by capturing input essential elements through ecosystem and plant processes that are active during most of the growing season (Manske 2012a).

In order to increase soil microorganism biomass on cropland ecosystems, the availability of large quantities of carbohydrate energy during most of the growing season will be needed, and the availability of a low cost procedure to measure microbial biomass will be needed. Soil microorganism biomass is difficult to measure directly. A usually reliable indirect measure of soil microbial biomass and biogeochemical activity is the quantity of mineral nitrogen available between mid June and mid July. The microbial biomass in cropland ecosystems should be large enough to mineralize a minimum of 100 pounds of nitrogen per acre (Manske 2012b).

Soil microorganism biomass is limited by the availability of energy from carbohydrates. The primary producers of the soil microbe food web are saprophytic, absorbing organic matter from dead material and exudated material. The quantity of carbohydrate energy from dead crop roots and stubble residue would support an extremely small microbial biomass. The quantity of carbohydrate energy in exudates released at a slow leakage rate into the soil through roots of actively growing crop plants will support a microbial biomass 20% to 30% of the desirable microorganism biomass. The quantity of carbohydrate energy from exudates that have been increased as a reaction to the removal of 25% to 33% of the aboveground plant biomass during vegetative growth stages will be sufficient to support a microorganism biomass large enough to mineralize 100 pounds of nitrogen per acre (Manske 2012b).

A large healthy biomass of soil microorganisms secrete large amounts of insoluable extracellular polysaccharides that have adhesive qualities that bind soil particles causing aggregation of soil. Increased soil aggregation enlarges soil pore size, and improves distribution and stabilization of soil particles. These improvements in soil quality cause increases in soil oxygenation, increases in water infiltration, and decreases in erodibility. Increased soil aggregation contributes to improved productivity (Manske 2007).

Increasing soil organic matter content by adding composted organic garbage, livestock manure, or anything similar with an equal weight and quality to the organic matter removed at harvest should be possible with existing technologies. Increasing the soil microorganism biomass to moderate levels for brief periods during the growing season should be possible with existing technologies. However, increasing the soil microorganism biomass to high levels for most of the growing season requires changes in cropping strategies. Large populations of soil microbes cannot exist solely on dead cropland residue. Large quantities of carbohydrate energy from exudates released into the soil through living plant roots is required. Persuading plants to exudate large quantities of carbohydrate energy into the soil requires partial defoliation of 25% to 33% of the aboveground biomass between the three and a half new leaf stage and the flower stage. The quantities of regular exudate leakage from undefoliated plants is insufficient, and only provides about 20% to 30% of the required exudate quantities. Low or moderate microbial populations would mineralize essential elements into the inorganic form at low or moderate quantities that would result in crop production below region yield potential. Restoration of cropland ecosystem soil quality requires the maintenance of a large microbial biomass that mineralize large quantities of organic matter converting large quantities of essential elements into the inorganic form that are available to crop plants that can then produce large yields of salable commodities. Improvement of cropland ecosystem soil quality and productivity resulting from the restoration of the soil biogeochemical processes will be possible through the development of management practices analogous to the management practices used to activate the biogeochemical processes of mixed grass prairie grazingland ecosystems (Manske 2012b).

Acknowledgment

I am grateful to Sheri Schneider for assistance in production of this manuscript.

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