

Enhancement of the Nitrogen Cycle Improves Native Rangeland

Llewellyn L. Manske PhD
Range Scientist
North Dakota State University
Dickinson Research Extension Center

Available soil mineral nitrogen is the major limiting factor of herbage growth on native rangelands (Wight and Black 1979). Rangeland soils, however, are not deficient of nitrogen. Most of the nitrogen in rangeland ecosystems is in the organic form. A large amount of the organic nitrogen is immobilized in living tissue of microorganisms, plants, and animals as essential constituents of proteins and nucleic acids. An additional large amount of the soil organic nitrogen is contained in the soil organic matter detritus that is at various stages of physical breakdown and decomposition and is derived from dead organisms, excreta, and sloughed material. A small portion of the soil nitrogen is in the mineral form as ammonium, nitrate, and nitrite. The amount of available mineral nitrogen in the soil is affected by the rate of mineralization of the organic nitrogen by soil microorganisms. A minimum rate of mineralization of about 100 pounds of mineral nitrogen per acre per year is required to sustain herbage production at potential levels on native rangeland (Wight and Black 1972). Mineralization at these high rates can not be obtained from traditional grazing practices (Wight and Black 1972). Grazing management specifically designed to enhance soil microorganism activity can be implemented to obtain mineralization rates of 100 pounds of mineral nitrogen per acre per year or greater. Enhancement of the nitrogen cycle, with increases in the quantity of available soil mineral nitrogen, increases herbage growth and production and improves new wealth generation from native rangeland natural resources.

The nitrogen cycle in rangeland ecosystems is complex. Nitrogen is versatile and has several oxidation states and can exist as a gas, a dissolved cation or anion, a precipitated salt, an adsorbed or interlayer ion in clay, and as dissolved or solid organic molecules of varying complexity (Russelle 1992). Nitrogen moves through a variety of biological and chemical pathways and the movement within the cycle is difficult to predict and highly variable among different climatic zones because the nitrogen cycle pathways are directly or indirectly influenced by regional temperature and moisture regimes. Biological pathways are also influenced by metabolic rates of microorganisms, plants, and animals (Russelle 1992). The nitrogen cycle in rangelands is open and has inputs (gains) that transfer in from outside sources and has outputs (losses) that transfer out of the ecosystem.

Nitrogen inputs on rangelands arrive through atmospheric pathways as wet deposits in rain, snow, or hail and as dry deposits of gases or minute particles. Lightning discharges cause atmospheric nitrogen (N_2) and oxygen (O_2) to combine and produce nitrogen oxides, mainly nitric acid (NO) and dinitrogen oxide (N_2O), that are deposited on rangeland in precipitation. Inorganic nitrogen, as ammonium (NH_4) and nitrate (NO_3), and complex organic compounds removed by erosive forces from distant soil surfaces are deposited on rangelands in precipitation, wind, and sometimes overland water movement. The ambient amount of wet and dry nitrogen deposition in temperate regions from natural sources is around 5 to 6 pounds per acre per year (Brady 1974). Nitrogen deposits from other sources are primarily nitrogen oxides expelled in the exhaust emissions from cars, aircraft, and factories. The amount of nitrogen deposits from sources related to anthropogenic activity is highly variable, influenced by distance and direction from population centers, and can range from 0 to 15 pounds per acre per year or greater (Gibson 2009).

Symbiotic and nonsymbiotic fixation of atmospheric nitrogen is an input source of nitrogen for some mesic grasslands but generally not for semiarid rangelands. Strains of symbiotic *Rhizobium* bacteria form nodules on the roots of legumes and can fix atmospheric dinitrogen gas (N_2) in soil air and synthesize it into complex forms. Some of this fixed nitrogen is required by the bacteria, some of the nitrogen can be available to the host plant, and some of the nitrogen can be passed into the surrounding soil by excretion or by the sloughing off of the roots with nodules (Brady 1974). Legumes are not an abundant component in native rangelands and the legumes that are present in mature soils have low levels of nodulation and may not fix nitrogen (Gibson 2009). A few nonsymbiotic soil microorganisms are able to fix atmospheric dinitrogen (N_2) from soil air into their body tissue (Brady 1974). Nitrogen fixation by free living soil bacteria in semiarid rangelands is not known to be important and considered to be insignificantly low or nonexistent (Legg 1995, Gibson 2009).

Potential outputs for nitrogen from rangeland ecosystems can be lost to the atmosphere through denitrification of mineral nitrogen, ammonia volatilization, and volatilization by fire; lost through

transfers by wind and water erosion of surface soil and by hydrologic leaching; and lost through animal production of both domesticated livestock and wildlife.

Denitrification is the reduction of inorganic nitrogen by removal of oxygen from the nitrite (NO_2) and nitrate (NO_3) mineral nitrogen to form gaseous nitrous oxides (NO and N_2O) or nonreactive dinitrogen gas (N_2) and can be mediated both chemically and biologically (Brady 1974). Losses from denitrification in rangelands is greatest in the nitrous oxide form (N_2O), followed by losses in the dinitrogen form (N_2). Losses in the nitric oxide form (NO) occur on rangelands only under acid conditions (Brady 1974). Chemical denitrification is of little importance in native rangelands unless nitrate is present in high concentrations (Russelle 1992). Biological denitrification occurs when soil microorganisms are deficient of oxygen as a result of poor drainage or poor soil structure causing soil saturation or lack of aeration. Denitrification probably accounts for only a small part of the total nitrogen losses from pastures and rangelands (Legg 1975, Gibson 2009).

Ammonia volatilization can occur near the soil surface during mineralization of soil organic nitrogen by soil microorganisms (Foth 1978). Gaseous ammonia (NH_3) forms as an intermediate stage and is usually readily hydrolyzed to form ammonium (NH_4) which is a stable form of mineral nitrogen. However, under conditions of increasing aridity and decreasing availability of hydrogen ions, the hydrolyzation process decreases and the amount of ammonia that escapes into the atmosphere by volatilization increases (Gibson 2009).

Nitrogen contained in aboveground herbage and litter is volatilized when rangelands are burned by prescribed fire and wild fire. Combustion causes nitrogen losses approaching 90%, primarily as ammonia (NH_3), dinitrogen oxide (N_2O), and other nitrogen oxides (Russelle 1992). Little belowground nitrogen is volatilized when the soil is moist during a burn, however, when the soil is dry, belowground temperatures can increase enough to denature protein, killing portions of the grass crowns and root material and volatilizing some belowground nitrogen.

Nitrogen in soil, litter, and organic detritus can be transferred from one area to another through movement by wind and water. The transferred nitrogen is a loss from one area and a gain at the deposition area. Nitrogen losses through erosion removal are variable and influenced by live plant density, litter cover, extent of branching fibrous root systems, and soil infiltration rates. The quantity of nitrogen lost through erosional movement can be

decreased with enhancement of the nitrogen cycle and improvement in productivity of the rangeland ecosystem (Russelle 1992).

Soluble nitrate (NO_3) moves downward in the soil profile with soil water. In mesic grasslands, nitrogen can be lost as a result of water movement below the rooting depth (Russelle 1992). None of the mineral nitrogen in western rangelands is lost by hydrologic leaching through the soil profile (Power 1970) because very little water moves below the three foot soil depth and water loss by leaching is low or nonexistent in arid and semiarid rangelands under cover of perennial vegetation (Brady 1974, Wight and Black 1979).

Livestock grazing semiarid rangelands in the Northern Plains consume about 25% of the aboveground herbage, leaving a significant part of the nitrogen absorbed by the growing vegetation in the remaining live aboveground herbage, the standing dead vegetation, and the litter. Most of the nitrogen consumed by grazing livestock and wildlife is returned to the soil surface in urine and feces waste. Almost all of the nitrogen in urine is immediately available to plants. A portion of the urea in urine can be volatilized in warm dry conditions (Gibson 2009). Grazing animals retain only a small amount of the nitrogen consumed, about 15% to 17% in a nonlactating animal and about 30% in a lactating animal (Russelle 1992). The quantity of nitrogen lost as animal product increases as enhancement of the nitrogen cycle improves productivity of the rangeland ecosystem.

Differences in nitrogen inputs and outputs on rangeland soils determine the quantity of net accumulation of nitrogen. The total nitrogen content in soils accumulates gradually over several thousand years. Organic matter accumulation is benefitted in northern soils because little or no chemical oxidation activity of organic matter takes place during the cold periods. The dark surface layer of most soils in the Northern Plains has an accumulation of 2% to 5% organic matter (Larson et al. 1968, Wright et al. 1982). An acre of soil 6 inches deep contains about 1000 pounds of nitrogen for each percent of organic matter (Foth 1978). Nitrogen content and percent organic matter decrease with soil depth. A net accumulation of 2 pounds of nitrogen per acre per year results in a soil with 5 tons of nitrogen per acre in 5000 years.

The nitrogen cycle within rangeland soils functions around the two processes of immobilization and mineralization. These processes take place simultaneously with plant growth, dieback, and decomposition (Legg 1975). Immobilization is the process of tying up nitrogen in organic forms.

Mineralization is the process of converting organic nitrogen into mineral (inorganic) nitrogen.

Biological immobilization of nitrogen occurs when autotrophic plants and soil microorganisms absorb inorganic nitrogen and build essential organic nitrogen compounds of amino acids and nucleic acids. Amino acids are building blocks of proteins that form enzymes, hormones, and important structural components of cells. Nucleic acids, deoxyribonucleic acid (DNA) and ribonucleic acid (RNA), are the genetic material that control all cellular functions and heredity. In rangeland soils, nitrogen is tied up in organic forms for three to four years (Power 1972). Biological immobilization of mineral nitrogen by plants and soil microorganisms is beneficial for rangeland ecosystems because about 95% of the total nitrogen is preserved within the soil as organic nitrogen and not subjected to great potential losses through denitrification and ammonia volatilization (Legg 1975, Gibson 2009).

Chemical immobilization of mineral nitrogen by adsorption of ammonium onto clay particles can be an advantage or a disadvantage for rangeland ecosystems depending on the type and amount of clay present. The ammonium ions are apparently the right size to fit into the cavities between crystal units normally occupied by potassium making the ammonium more or less a rigid part of the crystal (Brady 1974, Foth 1978). The type of clay mineral affects the retention of the ammonium. Clay materials with expanding lattices, such as vermiculite, illite, and montmorillonite, have greater surface area and adsorptive capacity for ammonium than clay minerals with nonexpanding lattices, such as kaolinite (Brady 1974, Legg 1975). Chemical immobilization of ammonium to clay material protects that portion of the soil mineral nitrogen from potential losses. The ammonium is slowly released from the clay and made available to plants and soil microorganisms. When the quantity of clay is too high or when the ammonium release rate is too slow, available mineral nitrogen may be too low to maintain ecosystem productivity at potential levels.

Mineralization occurs when organic nitrogen immobilized in living tissue or contained in soil organic matter detritus is processed by soil microorganisms to form mineral nitrogen. Mineralization consists of a series of reactions. Complex proteins and other organic nitrogen compounds are simplified by enzymatic digestion that hydrolyze the peptide bonds and liberate and degrade the amino acids by deamination to produce ammonia (NH_3) and carbon dioxide, or other low molecular weight carbon compounds (Power 1972, Brady 1974). Most of the released ammonia is readily

hydrolyzed into ammonium (NH_4) which becomes part of the inorganic nitrogen pool in the soil.

Some of the ammonium produced during the mineralization process by soil microorganisms or the ammonium released from adsorption to clay material is nitrified in a complex two stage process coordinated by two distinct groups of soil bacteria. Ammonium is nitrified by enzyme oxidation that releases energy for the first group of bacteria and produces nitrite (NO_2) and water. In short order, the second group of bacteria oxidize the nitrite by enzyme activity that releases energy and produces nitrate (NO_3) which becomes part of the inorganic nitrogen pool in the soil. The speed of this coordinated two stage nitrification process prevents accumulation of nitrite in the soil. Concentrations of nitrite are toxic to higher plants (Brady 1974).

The quantity of available soil mineral nitrogen varies cyclically with changes in soil temperature, 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 organic nitrogen mineralized by soil microorganisms and the quantity of mineral nitrogen immobilized by plants (Brady 1974, Legg 1975). The relationships between soil microorganism activity and phenology of plant growth activity results in a dynamic cycle of available mineral nitrogen (Goetz 1975). When soil microorganism activity is greater than plant growth activity, the quantity of available mineral nitrogen increases. When plant growth activity is greater than soil microorganism activity, the quantity of available mineral nitrogen decreases. This cycle in available soil mineral nitrogen results in three peaks and three low periods during the growing season (Whitman 1975). The quantity of mineral nitrogen increases an average of 25% to 50% between the low periods and the peaks in the cycle with some variations occurring on different range sites and at different soil depths (Goetz 1975).

Mineralization and nitrification processes of soil microorganism activity start slowly in the spring when the soil temperature permits formation of liquid water around 30° F. Available mineral nitrogen increases with increases in soil temperature and microorganism biomass reaching the first peak in mineral nitrogen around mid May just prior to start of rapid plant growth. The quantity of mineral nitrogen decreases rapidly with increasing plant growth rates during spring reaching the first low period during June and the first two weeks of July. The second peak in mineral nitrogen is reached at the end of the active growing season usually around late July or early August. A second low period in mineral nitrogen occurs from around mid August to mid or

late September when plants have slow growth rates and during growth and development of fall tillers and fall tiller buds that will produce the early plant growth during the subsequent growing season. The third peak in mineral nitrogen occurs around mid October just prior to the end of the perennial plant growing season during autumn. Mineral nitrogen declines during the third low period as winter freeze up approaches (Goetz 1975, Whitman 1975).

The greater the quantity of mineral nitrogen available during periods of active plant growth, the greater the quantity of herbage biomass production. Rangeland ecosystem biogeochemical processes that cycle nitrogen need to function at rates that provide 100 pounds of mineral nitrogen per acre to produce the minimum potential quantity of herbage biomass and need to provide 165 pounds of mineral nitrogen per acre to produce the maximum potential quantity of herbage biomass (Wight and Black 1972) (table 1).

Traditional management practices, like 6.0 month seasonlong, repeated seasonal, and deferred grazing, were designed to use rangelands as a source of grazable forage for livestock and, even when operated with strong land stewardship ethics, traditional practices do not provide mineral nitrogen at quantities great enough to produce the potential quantity of herbage. Rangelands managed for about 35 years with a moderately stocked 6.0 month seasonlong grazing practice provided 62 pounds of mineral nitrogen per acre (Manske 2009), rangelands managed with an unspecified traditional grazing practice provided 59 pounds of mineral nitrogen per acre (Wight and Black 1972), and rangelands managed for 35 years with a low to moderately stocked 4.5 to 5.0 month deferred grazing practice provided 31 pounds of mineral nitrogen per acre (Manske 2008) (table 1). Rangelands managed with traditional grazing practices provide mineral nitrogen at deficiency rates of less than 100 pounds per acre causing decreases in plant water use efficiency and reducing herbage biomass production an average of 49.6% per inch of precipitation (Wight and Black 1979) (table 1). As a consequence of traditional grazing practices providing low quantities of mineral nitrogen and producing less than potential quantities of herbage biomass, native rangelands are incorrectly considered to be low producing, low income generating, resources.

Grazing management that is designed to meet the biological requirements of the plants and soil microorganisms and to stimulate ecosystem biogeochemical processes provide greater quantities of mineral nitrogen than do traditional practices. During the seventh grazing season, rangelands managed with a three pasture twice-over rotation grazing system provided 178 pounds of mineral

nitrogen per acre (Manske 2008) (table 1). The greater quantity of mineral nitrogen resulted from greater soil microorganism activity. The twice-over rotation grazing system stimulated soil microorganism activity in the rhizosphere by increasing the quantity of plant fixed carbon exudated through grass roots into the rhizosphere. Removal of 25% to 33% of the leaf material by grazing livestock after the three and a half new leaf stage and before the flowering (anthesis) stage increased plant carbon exudates (Manske 2007). Soil microorganism growth and activity is limited by available carbon. Rhizosphere organisms increase in biomass and activity with increases in carbon. The rhizosphere volume on traditional grazing practices after twenty years of 6.0 month seasonlong and 4.5 month seasonlong was 50 and 68 cubic feet per acre, respectively (table 1). The rhizosphere volume was 227 cubic feet per acre on a twice-over rotation grazing system after twenty years (Manske 2008) (table 1). The greater rhizosphere organism biomass on rangelands managed with a twice-over rotation system had increased activity that mineralized and nitrified a greater quantity of organic nitrogen into mineral nitrogen. The greater quantity of available soil mineral nitrogen permitted the production of maximum potential herbage biomass, the growth of greater pounds of calf weight per acre, the generation of greater wealth per acre, and the improvement of native rangeland natural resources (Manske et al. 2008).

Table 1. Grazing management effects on mineral nitrogen and rhizosphere volume in native rangelands.

Standards for Mineral Nitrogen		Mineral Nitrogen	Source
Minimum potential herbage biomass		100 lbs/ac	Wight and Black 1972
Maximum potential herbage biomass		165 lbs/ac	Wight and Black 1972
Mineral nitrogen deficiency of less than 100 lbs/ac results in 49.6% reduction in herbage production per inch of precipitation.			Wight and Black 1979
Grazing Management		Mineral Nitrogen	
4.5-5.0 month Deferred	35 yrs	31 lbs/ac	Manske 2008
Traditional, not specified	long-term	59 lbs/ac	Wight and Black 1972
6.0 month Seasonlong	35 yrs	62 lbs/ac	Manske 2009
4.5 month Seasonlong	6 yrs	112 lbs/ac	Manske 2008
Twice-over Rotation	6 yrs	178 lbs/ac	Manske 2008
Grazing Management		Rhizosphere Volume	
6.0 month Seasonlong	20 yrs	50 ft ³ /ac	Manske 2008
4.5 month Seasonlong	20 yrs	68 ft ³ /ac	Manske 2008
Twice-over Rotation	20 yrs	227 ft ³ /ac	Manske 2008

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