A Brief Overview of Nutrient Cycling in Pastures

LIVESTOCK SYSTEMS GUIDE

Abstract: *Nutrients in a pasture system cycle through soil organisms, pasture plants, and grazing livestock. Appropriate management can enhance the nutrient cycle, increase productivity, and reduce costs. Two practical indicators of soil health are the number of earthworms and the percentage of organic matter in the soil. A diversity of pasture plants growing on healthy soils use sunlight and the nutrient resources in the soil to effectively produce animal feed. Paddock design and stocking density can also affect the efficiency of nutrient cycling in a pasture system. Supplementation of natural fertility, based on soil tests, balances the soil's mineral composition, resulting in better plant and animal growth and increased soil health.*

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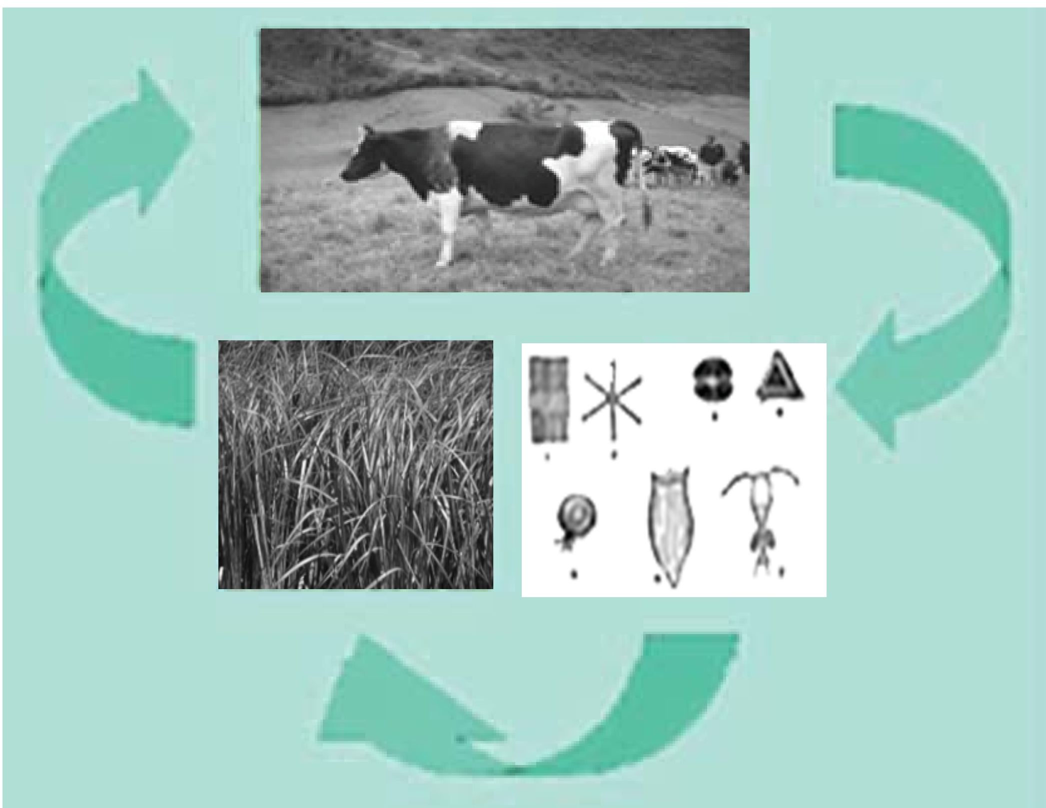

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Introduction

When nutrients cycle efficiently in a pasture system, they move through various soil organisms and pasture plants, then through the grazing animals, and back to the soil again as manure and urine. This publication provides a general outline of the nutrient cycle, and gives pasture managers some guidelines for working with the many elements of these complex systems. For more detail and more technical information, refer to the companion ATTRA publication, *Nutrient Cycling in Pastures*.

Pasture managers can effectively increase soil fertility by understanding the functions of the plants and animals living in and on the soil. Not only can soil organisms generate mineral nutrients or make them available, but these same minerals can also be recycled several times in a growing season, if the soil ecosystem is healthy and plant cover is optimal. With good management, nutrients can cycle quickly with minimal losses to air and water. Less fertilizer will be required, and this means increased profitability for the entire farm.

Three different groups of living organisms drive the nutrient cycle: soil organisms, pasture plants, and grazing livestock. Each will be discussed separately below. They all work together to produce good-quality soils, which in turn produce good-quality pastures. Good-quality soils don't erode, since water flows quickly into the ground and is stored there. Good-quality pastures are springy underfoot, with deep green forage that covers the soil and a moderate amount of dead residue under the canopy. They produce nutritious forage with balanced mineral levels. Livestock find these forages palatable and thrive on them. Animal manure and plant residues quickly break down to be used again.

Producers create this kind of soil through good management. They use smart grazing strategies. They test their soils regularly and apply fertilizers, lime, and organic amendments as needed. They monitor the results of these decisions and make note of their observations for future reference. They understand their forages and adjust stocking rates and paddock rest periods. They make harvesting and seeding decisions to maintain and improve their soil and pasture resources.

Soil Organisms and Nutrient Cycling

The soil is alive with organisms, ranging from visible insects and earthworms to microscopic bacteria and fungi. These living organisms are working for the grass farmer, to whom they are extremely important. We might even refer to them as *soil livestock*. In fact, the soil can be viewed as home to a great complexity of life, rather than just a medium to support plants. An acre of living soil may contain 900 pounds of earthworms, 2400 pounds of fungi, 1500 pounds of bacteria, 133 pounds of protozoa, 890 pounds of arthropods and algae, and even small mammals in some cases (1). An understanding of underground biological cycling can enable the pasture manager to benefit from this herd of soil livestock.

Soil bacteria are the most numerous, with every gram of soil containing at least a million of these tiny one-celled organisms. There are many different species of bacteria, each with its own role in the soil environment. One of the major benefits bacteria provide for plants is to help them take up nutrients. One of the primary ways they do this is by releasing nutrients from organic matter and soil minerals. Certain species release nitrogen, sulfur, phosphorus, and trace elements from organic matter. Other species break down some soil minerals and release potassium, phosphorus, magnesium, calcium, and iron. Still other spcies make and release plant growth hormones, which stimulate root activity. Some bacteria, either living inside the roots of legumes or free-living in the soil, fix nitrogen. Other services provided to plants by various species of bacteria include improving soil structure, fighting root diseases, and detoxifying the soil.

Actinomycetes are thread-like bacteria that look like fungi. While not as numerous as other bacteria, they perform vital roles in the soil. Like other bacteria, they help decompose organic matter into humus, releasing nutrients. They also produce antibiotics to fight root diseases. And they are responsible for the sweet earthy smell of biologically active soil.

Fungi come in many different species, sizes, and shapes in soil. Some species appear as thread-like colonies, while others are one-celled yeasts. Slime molds and mushrooms are also fungi. Many fungi aid plants by breaking down organic matter or by releasing nutrients from soil minerals. Some produce hormones and antibiotics that enhance root growth and provide disease suppression. There are even species of fungi that trap harmful plant-parasitic nematodes. Mycorrhizae are fungi that live either on or in plant roots and act to extend the reach of root hairs into the soil. Mycorrhizae increase the uptake of water and nutrients, especially in soils with nutrient deficiencies. The fungi, in turn, benefit by taking nutrients and carbohydrates from the plant roots they live with.

Many species of algae also live in the soil. Unlike most other soil organisms, algae produce their own food through photosynthesis. They appear as a greenish film on the soil surface following a rain. Their primary role is to improve soil structure by producing sticky materials that glue soil particles together into water-stable aggregates. A soil aggregate looks like a minature crumb of granola. In addition, some species of algae (the blue-greens) can fix nitrogen, some of which is later released to plant roots.

Protozoa are free-living animals that crawl or swim in the water between soil particles. Many soil protozoa species are predatory, eating other microbes. By consuming bacteria, protozoa speed up the release of nitrogen and other nutrients through their waste products.

Nematodes are abundant in most soils, and only a few species are harmful to plants. The harmless species eat decaying plant litter, bacteria, fungi, algae, protozoa, and other nematodes. Like the other soil predators, nematodes speed the rate of nutrient cycling.

These living organisms are working for the grass farmer, to whom they are extremely important. We might even refer to them as *soil livestock*.

Earthworms are good indicators of soil health. Research in New Zealand pastures has repeatedly shown improved soil qualities where worms thrive. Studies have also proved that forage production nearly doubles when worms are introduced and establish themselves in pastures. This higher production might be attributed to other related changes, not just the direct activity of the worms themselves. Nevertheless, there is a demonstrated correlation between worm population and forage production (2).

Earthworm burrows enhance water infiltration and soil aeration. Earthworms pass soil, organic matter, and soil microbes through their digestive systems as they move through the soil. This process increases the soil's soluble nutrient content considerably. Worms eat dead plant material left on top of the soil and redistribute the organic matter and plant nutrients throughout the soil horizon. Research shows that a thick layer of dead organic material remains on the surface in pastures without any worms. Earthworms also secrete a material that stimulates plant growth. Some increase in plant growth, as well as the improved soil quality, can be attributed to this substance. In addition, a Dutch study revealed that worms reduced the transmission of some parasitic nematodes in cow pats (3).

As Charles Griffith of the Noble Foundation has said, you can never have too many earthworms. He was working toward a goal of 25 per square foot, but reports from New Zealand mention 40 per square foot in soils where worms were introduced only seven years earlier (4). Earthworms thrive where there is no tillage, especially in the spring and fall, their most active periods. They prefer a near-neutral pH, moist soil, and plenty of plant residue on top. They are sensitive to some pesticides. Fertilizers applied to the soil surface are often beneficial, but anhydrous ammonia is deadly, and tillage destroys nightcrawler burrows. Efforts to protect and increase worm populations will be rewarded with healthier, more productive pastures.

In addition to earthworms, there are many other species of soil organisms visible to the naked eye. Among them are dung beetles, sowbugs, millipedes, centipedes, slugs, snails, and springtails. These are the primary decomposers. They start eating the large particles of plant residue. Some bury residue, bringing it in contact with other soil organisms, which further decompose it. The springtails eat mostly fungi, and their waste is rich in plant nutrients. All these organisms—from the tiny bacteria up to the large earthworms and snails—function together in a whole–soil ecosystem. Because humans cannot see most of the critters living in the soil and may not take time to observe the visible ones, it is easy to forget about them. They are present in biologically active soils and perform many useful functions, if pastures are managed for their survival.

Organic Matter is Essential to Soil Health

Organic matter is critical for storing water and nutrients in the soil. It holds nutrients in plant-available forms that don't easily wash away. It creates an open soil structure into which water, dissolved minerals, and oxygen can move, ready for plants to use. It provides further nutrient storage in the soil and can disable certain plant toxins. In addition, beneficial soil organisms depend upon organic matter as a source of food. These countless tiny plants and animals create an ecosystem that releases mineral nutrients, increases their availability to plants, and helps protect plant roots from disease.

Testing for soil organic matter (OM) is a simple way to make sure there is a functioning community of organisms in the soil. All the organisms mentioned above, except algae, depend on organic matter for their food. The primary decomposers start with raw plant residues and manure. Their by-products are eaten by other species whose wastes feed still other microbes. After moving through several species, these raw materials become soluble plant nutrients and humus. The humus contributes to well-structured soil, which in turn produces high-quality forage. It is clear that when this soil ecosystem is working, there are many benefits to the pasture system visible above ground. The complex ecosystem underground would be hard to evaluate, but soil organic matter, as measured in regular soil tests, is a simplified way to monitor the health of this invisible world.

The organic matter test can be requested through local Extension facilities. This kind of soil analysis measures, by weight, the percentage of soil that is OM. Organic matter includes minerals that are part of living organisms, as well as dead plant material that has not yet been digested. Because organic matter levels are harder to maintain in warmer, more humid climates, what constitutes a "high" or "low" percentage will vary in different parts of the country. Local Extension agents or soil scientists can help define relative values. A single test will show a beginning point, and subsequent soil tests can indicate whether progress is being made toward a higher level of soil organic matter.

Maintaining or building organic matter is the first step to developing soil humus. Humus results from the final stages of organic matter decomposition. Favorable biological processes which decompose the organic matter into humus can be limited or even stopped by lack of nitrogen, lack of oxygen, unfavorable temperature, or unfavorable pH. Once stable humus has accumulated in the soil, it has a host of beneficial effects on plants. These positive effects are directly related to the presence and diversity of microbial life.

Benefits of a humus-rich soil include:

- Granulation of soil particles into water-stable aggregates
- Decreased crusting
- Improved internal drainage
- Better water infiltration
- Fixation of atmospheric nitrogen
- Release of bound nutrients
- Increased water and nutrient storage capacity

Pasture Plants Also Cycle Nutrients

Rhizobium bacteria live in legume root nodules and convert nitrogen from the air into forms the legume can use. This nitrogen is used by the plant and generally does not become available to nearby plants until the legume dies. Some of the nitrogen fixed by white clover, however, is available as soon as four months into the season. With red clover, the interval is six months, and alfalfa-fixed nitrogen takes 6 to 12 months to become available. Although white clover is credited with fixing less nitrogen than either red clover or alfalfa, if that nitrogen is available sooner, with efficient nutrient cycling it could be used more than once in a growing season. It therefore becomes just as important as other legumes as a source of new nitrogen in the nutrient cycle. In addition, some nodules separate naturally from the legume roots during a grazing cycle, thus becoming available to other plants. Some legumes have "leaky" nodules and share more of their fixed nitrogen than others.

A nitrogen molecule can be fixed by white clover in one day. If eaten by a cow and excreted in urine, it could take as little as two weeks before it's again available in plant tissue. If the clover isn't eaten directly, the nitrogen that it harvested from the air may naturally become available to nearby grasses in as little as four months. Nitrogen in a leaf that falls on biologically active soil can be used again in the same growing season.

A final way in which nutrients become available to the forage plants (and thus to the grazing animal) is through the action of deeply rooted plants. Trees, many broadleaf weeds, and forages such as alfalfa have taproots that go deep into the soil horizon where some grass roots cannot reach. The nutrients from these deeper soil levels are used by the plant, but become available at the soil surface once the tree leaves fall or the weeds die, decompose, and release their nutrients.

The roots constitute at least half the weight of a grass plant. Many native warm-season perennial grasses have root systems that reach six feet or more into the soil horizon. They occupy a huge underground area and form a network that holds the soil in place. Every year 20–50% of this mass, as well as all of the top growth in temperate climates, dies and becomes organic matter which, in biologically active soil, is broken down quickly. Cool-season grasses also contribute organic matter through root and shoot dieback.

Grazing Livestock Affect Pasture Nutrient Cycles

Livestock feeding on pasture use a small proportion of the minerals they ingest in forages to build bones, meat, and hide. The rest is excreted in dung and urine. In general, urine contains most of the nitrogen (N) and potassium (K) wastes, and dung contains most of the phosphorus (P) the animals don't use. Refer to the box on page six to learn about the value of urine and dung in pastures.

Nutrients in urine are soluble and move in the soil solution to the roots. When N and K are present at higher levels in the feed, they are excreted in manure as well. The liquid forms can be taken up by a plant at once and are then very quickly available again as food. Sheep, which do not avoid urine spots as cattle do, can immediately cycle this mineral again.

Value Of NPK In Manure And Urine

One 1000-pound cow produces 50–60 lbs. of manure and urine per day, which contains:

0.35 lb. N @ 24¢/lb. = 8¢ N
0.23 lb. P @ 22¢/lb. = 5¢ P
0.28 lb. K @ 14¢/lb. = 4¢ K
Total NPK = 17¢

Therefore:

10 cows ⇒ $ 1.70/day
100 cows ⇒ $17.00/day
500 cows ⇒ $85.00/day

Note: If you add the value of organic matter and trace minerals in the manure, the total value of the manure doubles!

Source: Salatin, Joel. 1993. One Cow Day of Manure: What's It Worth. Stockman Grass Farmer. September. p. 11.

Phosphorus and some other minerals cycle through animals primarily in manure. It can take from six months to two years for manure to break down and for the phosphorus to cycle back into the plants. The speed of the cycle is affected by various biological agents as well as by mechanical means. Dung beetles bury manure with their eggs in burrows. This activity not only places the minerals back into t roots can use them but it prevents fly eggs from hatching as well. Some pesticides designed to control livestock parasites unfortunately kill dung beetles as well. This side effect can deal a serious blow to the ability of the natural ecosystem to function. For more information on this subject, call and request *Dung Beetle Benefits in the Pasture Ecosystem* or find it on the ATTRA website (http://www.attra.ncat.org).

Other agents that help to break up manure piles include ants, birds, and earthworms. Pesticides that are lethal to these non-target species can thus have unforeseen negative consequences for nutrient availability. If dragging or clipping is economical, these operations physically scatter the dung so that smaller organisms can cycle it. The potential of creating a larger area of forage rejection, however, is a consideration. Another negative effect is that more nutrients are lost into the air during mechanical scattering.

To recapture and evenly distribute these nutrients for soil organisms and plants to use requires some knowledge about grazing behavior. In smaller paddocks, with high stock density, urine and dung are more evenly distributed than in large ones. Livestock are less selective in their grazing habits and space themselves more evenly within the area allotted for a grazing period. They will graze closer to dung piles and exhibit less avoidance of urine spots so that more forage is used for animal production.

In large areas, cattle act as a herd and go to water together. When water is available nearby, however, animals drink individually and return to graze in other areas. If they must travel in a lane to the water, manure will concentrate in these non-productive areas en route. When there is not enough room at the water tank for all to water at once, those waiting will manure that area, concentrating nutrients where they are less likely to contribute to plant and animal productivity.

Good management helps distribute nutrients that will feed soil microbes and encourage healthy soil ecosystems. Locating water, minerals, shade, and fly-control devices in different parts of the paddock also discourages nutrient concentration. It is even more beneficial if these high-use areas can be relocated for each grazing cycle or placed in areas that would not otherwise attract livestock use. Supplemental feed, likewise, should be placed either where nutrients are needed or under the fence. The location should vary with each feeding.

Nutrient Cycling in Relation to Other Natural Cycles

Two other cycles—water and energy—interact with the nutrient cycle. They are separated for purposes of discussion here, but in reality they function as a whole system.

Water Cycle

Water is a nutrient, in one sense, since it is one of the raw ingredients used by plants to make carbohydrates. It is also key to nutrient cycling because plant nutrients are soluble and move with water. Downward leaching of plant nutrients occurs with water movement. Soil itself moves in water, taking with it insoluble nutrients such as phosphorus. The area around roots must be moist, since nutrients are taken up dissolved in water.

Management determines how effective the water cycle will be in pastures. If rainwater can enter the soil easily, runoff losses are less. Maximum infiltration of rainfall keeps groundwater tables charged up, wells running year round, and drought damage to a minimum.

Soil surface conditions that foster high rainwater intake are abundant ground cover (by living plants and surface litter) and good soil aggregation. The best-aggregated soils are those that have been in well-managed perennial grass (5). Though aggregation can be maintained under crops, the perennial activity of grass provides both aggregate-forming processes and aggregate-stabilizing humus.

A grass sod extends a mass of fine roots throughout the topsoil. The grass sod also provides protection from raindrop impact. A moderate amount of thatch continually provides food for soil microorganisms and earthworms that generate the glue-like substances that bind aggregates into water-stable units. The dead material, as well as the plants themselves, shade the soil, maintaining a cooler temperature and higher humidity at the soil surface.

Conditions that reduce water intake and percolation are bare ground, surface crusting, compaction, and soil erosion. These conditions are not usually present in well-managed perennial pastures. Bare ground leads to erosion, crusting, and weeds. Crusting seals the soil surface when the soil aggregates break down. Excessive trampling—especially in wet conditions—and the impact of falling raindrops on bare soil are two common causes of crusting. Therefore, it is important to move water sources, feedbunks, and minerals before bare ground and crusting develop.

Energy Cycle

The energy cycle is powered by sunlight, which plants convert into carbohydrates. In order to capture the most solar energy, the plant canopy needs to be very dense. If the pasture has both broadleaf plants and grasses, the different leaf orientations further increase energy transformation. Taller plants receive light, even at the extreme angles of sunrise and sunset. Horizontal leaves capture the noon sun better than upright grass leaves. Increased efficiency in energy conversion can be achieved if the pasture is considered a three-dimensional solar collector. Even trees, if they are trimmed high and do not make dense shade, contribute to such a system.

Energy from plants is also transferred into the soil ecosystem through the death and decay of plant roots and residue. The plant roots and residue are decomposed first by soil-dwelling insects and other primary decomposers. The waste and by-products from the primary decomposers are broken down still further by secondary decomposers. Finally the components of the residue become humus. At each step of the decomposition process, energy is either being used to create the next generation of decomposer or is lost as heat. The energy cycle and the nutrient and water cycles require a biologically active soil to function.

A thick stand of green plants covering the soil for as long a time as possible creates high energy

Farm Nutrient Budget

Nutrients imported to the farm in:
- Purchased livestock
- Chemical fertilizers
- Manures from off-farm (credit for multiple years)
- Livestock feed (grain, hay)
- Wind and water

Nutrients generated on the farm:
- Atmospheric nitrogen captured by legumes
- Rock minerals dissolved by microbial acids
- Subsoil minerals mined by deep roots of trees and other plants
- Nutrients made available to the crop by changes in pH

Nutrients exported from the farm:
- In products sold (crops, livestock)
- By wind and water (erosion)
- By leaching into groundwater
- Volatilized as gas

flow. This good-quality forage, provided to livestock at the right stage of maturity, is the next link in the energy cycle. Livestock convert plant material into meat, milk, and fiber. The leftovers become urine and manure. Livestock products are sold, and the waste products again cycle through the decomposer organisms. Minimal loss of energy depends on proper stocking rates, good decisions about when animals are moved, and how much rest the plants require.

Supplementing the Nutrient Cycle

One of the first steps in assessing the nutrient cycle on any farm is to consider nutrient inputs and outputs. In what forms do nutrients enter the farm? What nutrients leave and in what form? What nutrients are generated or made available on the farm? The box above provides some examples.

Lime is a particularly important amendment in pasture management. While it has always been considered necessary for adjusting pH, there is growing evidence that the amount of calcium has important consequences for plant production and animal health. Allan Nation, editor of *The Stockman Grass Farmer* and student of grass-based livestock systems, listed many reasons to apply agricultural lime annually. His list is reproduced below.

Soil tests, taken according to recommended procedures (consult Extension), provide a basic analysis of plant nutrient levels in a pasture. Fertilizer recommendations that accompany test results, however, are typically based on the assumption that forages will be harvested and removed from the area. In a grazing system this is not necessarily so.

Lime

200–500 lbs. of finely ground, face-powder-consistency ag lime applied annually:
- Helps prevent weeds such as dandelion, plantain, chickweed, and buttercup.
- Helps with the movement and absorption of phosphorus, nitrogen, and magnesium.
- Benefits bacteria, fungi, protozoa and other soil life so important for nutrient cycling.
- Releases important trace and growth nutrients by its pH-altering effect.
- Helps clover, which requires twice the calcium of grass. Abundant calcium is necessary for clover nodulation. No lime, little clover.
- Creates soil tilth and structure so that air and water can move more freely through soil by causing clay particles to stick together. Soil must be able to breathe to grow great grass.
- Allows pastures to hang on longer in a drought.
- Improves the palatability of grass and clover, makes the pasture softer for animals to graze, and lessens grass-pulling in new stands.
- Reportedly makes an animal more docile and content.

Source: Nation, Allan. 1995. Quality Pasture – Part II. Stockman Grass Farmer. January. p. 13.

Supplementing the nutrient cycle with commercial fertilizers, compost, or manure can increase both plant and animal production, which will, in turn, increase soil organic matter. In the early years of a pasture improvement plan, adding small amounts of fertilizer several times during the growing season is a good way to increase the amount of available forage. With good grazing management, more forage will translate into more pounds of livestock as well as increased soil organic matter.

To back up a fertilization program, forage samples can be taken to see what effect the fertilizer has had. Strategic forage-tissue testing can be done by taking samples between areas of poor and good growth or by making before- and after-fertilizer comparisons. County Extension agents or private consultants can explain how to take a forage sample. Because samples are analyzed for the purpose of ration balancing or to assess actual mineral content, it is necessary to specify the latter to learn whether fertilizers are achieving their purpose. More information on soils is available in the ATTRA publications *Sustainable Soil Management*, *Alternative Soil Testing Laboratories* and *Assessing the Pasture Soil Resource*.

Sole reliance on commercial fertilizer short-circuits the natural mineral cycle. High fertilization coupled with frequent harvesting of hay speeds organic matter decomposition and releases minerals faster than plants growing on the site can absorb them. As a result, nutrients are leached deeper into the soil, out of the reach of plant roots, or they are lost to run off. The use of some commercial fertilizer is always an option to be exercised when necessary. However, continuing to look for ways to use natural systems to produce nutritious forage and healthy animals, while lessening one's dependence on purchased, non-renewable resources, is worthwhile.

Conclusion

This publication has described the many paths travelled by pasture nutrients. While some minerals leave the farm as animal products, the majority move through a series of living beings in a continuous cycle. Some nutrients escape to the air, some are lost to water erosion, and some leach down past the reach of forage plant roots. The grazier who understands these cycles and their interactions can, by making smart daily decisions, retain more nutrients on site.

The health and growth of the grazing livestock depend on high-quality pastures, which in turn spring from the soil "livestock" in a balanced underground ecosystem. Soil organic matter and earthworm numbers are simple indicators that producers can use to monitor soil health. Good grazing management, based in part on a basic understanding of grazing behavior, combined with a knowledge of how animals affect the whole pasture system, contributes to lush pastures that livestock need only to harvest. Then, with good marketing, profit is the natural result!

For more in-depth discussion of the topics raised in this publication, consult the companion ATTRA booklet, *Nutrient Cycling in Pastures*. Some other good resources are listed below.

References

1) Pimentel, David et al. 1995. Environmental and economic costs of soil erosion and conservation benefits. Science. Vol. 267, No. 24. p. 1117–1122.

2) Stockdill, S.M.J. 1966. The effect of earthworms on pastures. Proceedings: New Zealand Ecological Society. Volume 13. p. 68–75.

3) Gronvold, Jorn. 1987. Field experiment on the ability of earthworms (Lumbrididae) to reduce the transmission of infective larvae of Cooperia oncophora (Trichostrongylidae) from cow pats to grass. Journal of Parasitology. Vol. 73, No. 6. p. 1133–1137.

4) Stockdill, S.M.J. 1959. Earthworms improve pasture growth. New Zealand Journal of Agriculture. March. p. 227–233.

5) Allison, F.E. 1968. Soil aggregation—some facts and fallacies as seen by a microbiologist. Soil Science. Vol. 106, No. 2. p. 136–143.

Further Resources

Proceedings:

Joost, Richard E. and Craig A. Roberts. 1996. **Nutrient Cycling in Forage Systems**. Proceedings of a Symposium held March 7–8, 1996, Columbia, MO. Potash and Phosphate Institute and Foundation for Agronomic Research, Manhattan, KS. 243 p.

Anyone interested in pursuing this subject further should obtain a copy of this book. It contains many bibliographic references. Available for $15 ppd. from:

Potash and Phosphate Institute
772 22nd Ave. S.
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Periodicals:

These carry articles on practical aspects of grazing management, including nutrient cycling.

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Web Sites:

Soil Foodweb, Inc.
http://www.soilfoodweb.com/index.html

More detail on the underground soil ecosystem and its above-ground interactions can be found on this website.

Related ATTRA Publications
Nutrient Cycling in Pastures
Assessing the Pasture Soil Resource
Sustainable Pasture Management
Rotational Grazing
Dung Beetle Benefits in the Pasture Ecosystem

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