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Pasture Ecology:
Managing Things That We Cannot See.

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As pasture-based livestock producers we are in the business of harvesting solar energy and converting it to food and fiber products for people. We manage plants to optimize harvesting solar energy, animals to transfer that energy into livestock products, and cycling of mineral nutrients in the landscape to make our businesses socially, economically, and environmentally sustainable. We are pasture ecosystem managers.

Most of our day-to-day efforts are spent with the livestock, managing the above ground portion of the pasture community to ensure that the livestock are properly fed. However, there is more biomass and biological activity below ground than above (Table 1).

Let's visit an old pasture and look at what is going on down below. We will see how this subterranean activity helps us achieve our goals and how proper above ground management can benefit the soil community.

Citizens of the soil community

Each plant, animal, bacteria, protozoa, and fungus has its niche or place in the pasture ecosystem. Each has an optimum physical and chemical environment and habitat. The habitat provides adequate food and cover, allowing the species to reproduce and maintain itself. The environment is based on the climate, soil texture, position in the landscape, and management.

The food chain (tropic levels or food web) is composed of primary producers who fix energy from the sun and all the other organisms that eat each other to get their part of this fixed solar energy. These are the primary consumers, higher level consumers or predators, omnivores, and parasites, and detritus feeders or decomposers. Here is a short introduction to the citizens of the pasture soil community (Figure 1)

Plant roots are an essential portion of the above ground producers. Roots gather water and nutrients for the plant and provide a major source of live and dead organic matter for food to soil organisms. Legumes within this group, with their symbiotic rhizobia bacteria, fix nitrogen from the air and provide it to the rest of the pasture community. Algae and moss are other primary producers that provide organic matter to the community.

Earthworms eat dead plant material (detritus). They are opportunistic predators when they consumer soil containing bacteria, protozoa, nematodes, fungus. They provide the ecological functions of shredding large pieces of organic matter making it more accessible to bacteria and fungus. They aerate and invert the soil, improving soil drainage, and aggregation of soil particles. They become food for birds, moles, skunks, and carnivorous slugs and nematodes.

Slugs and snails are consumers of live plant material with some carnivorous species being predators of earthworms and other slugs. They provide the service of shredding large pieces of organic matter into smaller pieces. They are food for birds, mice, daddy longlegs, beetles, and firefly larvae (glow worms).

Nematodes are consumers of plant roots and algae; predators of bacteria, protozoa, fungus, and nematodes, and parasites of insect larva, slugs, and earthworms. They provide an important function in the nitrogen cycle by eating bacteria and releasing nitrogen back into the soil for plants and other organisms. They are food for other nematodes, fungus, and mites.

Woodlice feed on dead plant material. They are shredders of course organic matter. They are food for birds and spiders.

Spiders are predators. **Mites** are consumers of algae and predators of nematodes, springtails, fungi, insect larva and eggs, and nematodes. Some species are detritus feeders while others are insect parasites.

Centipedes are predators of insects, slugs, and worms. **Millipedes** predominately eat detritus and fungus but sometimes are consumers of live plants and their seeds.

There are a number of insects that act as consumers and predators in the soil community.

Spring tails consume dead organic matter and fungus. Some consume plant seedlings, small nematodes, and dung of other soil animals. They are food for ants.

Beetles, such as the clover root curculio, are consumers of live plants. Some beetles are predators consuming other insects, earthworms, and snails. Other beetles, such as carrion and dung beetles, are detritus feeders. These beetles provide the ecological function of soil aeration, soil inversion and nutrient cycling in the community.

Ants are consumers of live plants and “farm” aphids for their honey dew. They also consume fungus and are predators of other soil organisms. They provide the function of soil inversion, providing improved soil aeration and water infiltration.

Termites consume dead plant material and are shredders of course organic matter. They digest cellulose using gut bacteria similar to a cow and provide the functions of soil aeration and soil inversion.

Bacteria are central participants in the nitrogen cycle. As symbiotic consumers in root nodules they use sugar provided by the plant as energy to fix nitrogen from the air into ammonia. This is passed on to the plant for making protein. Other bacteria are detritus feeders and break proteins down into ammonia while other bacterial convert ammonia to nitrate. Bacteria are food for protozoa and nematodes.

Actinomycetes look like fungus but are closely related to bacteria. Some species live on dead organic matter and are able to decompose the more resistant cellulose and phospholipids. Some species form symbiotic relations with plants and fix nitrogen while others are plant parasites.

Protozoa come in three forms; ciliates, amoeba, flagellates. Their main food source is bacteria. They are food for nematodes.

Fungus come as molds, mushrooms, and **mycorrhizae**. Fungi are decomposers of dead organic matter. Some fungi are predators of nematodes. The mycorrhizae fungi are a very important group of fungus. In their symbiotic relation with higher plants they provide mineral nutrients to the plant in exchange for energy and protein. Mycorrhizal fungi may cover the surface of plant roots (ectomycorrhizal) or enter inside the plant root cells (endomycorrhizal). Fungi produce glomalin, a glue-like material that is essential in the formation of soil aggregates. Fungi can decompose the more resistant organic matter such as cellulose and lignin.

Energy flow and nutrient cycles

So how do all of these citizens work together to help us manage our pastures? Their help revolves around solar energy flow in the ecosystem and nutrient cycling.

The green leaves of plants capture solar radiation through photosynthesis. They take carbon from the air and water from the soil and lock the energy in sugar while releasing oxygen to the atmosphere. The plants take the sugar and add nitrogen supplied from the soil or rhizobia bacteria if a legume (actinomycetes in some plants) to make proteins. The plants use these sugars and proteins to grow new leaves, stems, and roots. This metabolism requires the use of all the macro (N, P, K, S, Ca, Mg) and micro (Cu, Zn, Mn, Mo, Fe, B) nutrient minerals that are part of the enzyme systems in the plant. Plants are the primary producers in the pasture food web.

We often talk of ecological cycles with the various mineral cycles being separate from the carbon cycle. Carbon in the organic form is participating in the flow of energy. Other minerals are cycled in unison with organic carbon in plants and animals, at different rates and following different paths (Figure 2).

When a cow grazes the pasture, plants slough some roots while they are in the process of growing new leaves. Along with the roots clover plants drop some of their nodules. Earthworms eat these dead roots as they burrow through the soil while bacteria decompose dead roots and nodules that the earthworms do not eat. Later earthworms may end up consuming these bacteria as they go back through the soil.

Some bacteria prefer the highly digestible sugars and proteins while other bacteria prefer the readily digestible fiber; similar to bacteria in the cow's rumen. After the really digestible parts are digested, fungus and actinomycetes go to work digesting the less digestible fiber and lignin. All of this activity is necessary for the decomposition of dead plant material to return the mineral nutrients to the soil to be used again by plants. This is the process of nutrient cycling.

During grazing cows also treaded down part of the pasture sward. This material likewise is consumed by earthworms and detritus feeding insects, mites, bacteria, and fungus releasing C back to the air as they use the carbohydrates for energy and the protein nitrogen and minerals to sustain themselves. When organic matter energy is in good supply bacteria hold onto the nitrogen, divide, and make a whole lot more of themselves. Then when predatory nematodes and protozoa come alone they eat the bacteria and release a large part of the nitrogen (what that they don't need) back into the soil where it is available for plants to use.

Environments and niches

As we walk across the upper pasture we notice that different grasses, forbs, and legumes grow best in different parts of the landscape. On the well-drained uplands orchardgrass is abundant while in a wet area we find a stand of reed canarygrass. These different sites present different soil environments. The plants that do well on a part of the pasture are those adapted to the soil chemical and physical environment in that area. They are also tolerant of the timing and intensity of grazing placed on them by the animals as controlled by the farmer. These plants have found their niche or place in the pasture community.

Some plants are more abundant during one part of the year and appear to be replaced by other plants during another part of the year. For example in warm areas white clover does well in the spring and summer while annual lespedeza is more prevalent during the heat of the summer. This is a case of two species using the same niche but separated temporally (niches in the same physical space but separated in time) due to environmental temperature.

The same principles apply below ground. There are many species of bacteria, protozoa and other microorganisms that have the same ecological function in the soil. Some do better where the soil is high pH others do better where the soil is lower in pH. Some do best when the soil is cool others do best when the soil is warm. Having high species diversity is good since it ensures good microbiological activity across a range of environmental conditions.

Cows also drop dung and urine back on the soil surface. Dung is the residue of the forage that the rumen bacteria and protozoa and acid stomach did not digest. Urine contains the nitrogen that was excess to the cows ability to convert rumen nitrogen to bacterial protein and protein that was excess to the cow's need for growth and/or milk production.

Dung is quickly inhabited by dung beetles, fly larva, rove beetles that eat fly larva, earthworms, and bacteria. One group of dung beetles lays its eggs in the cow pie while another takes the dung and move it into burrows in the soil under the cow pie to lay eggs. A third group of dung beetles take small balls of dung and roll them away for burial in the soil as food for their larva. These dung beetles are demonstrating different physical niches or niches separated in space. Different species of dung beetles within these groups use the dung at different times of the year demonstrating different temporal niches. After a while fungus and actinomycetes invade the cow pie and help decompose the more resistant forms of carbon.

Soil Moisture a controlling factor

All of this biological activity affects plant productivity by cycling nutrients. It also has major effects the soil portion of the water cycle. Earthworms and dung beetles assist by making passageways from the surface into the lower soil. Earthworms, bacteria and fungus assist by making glues that hold soil particles together making them stable when wet so that the soil has more, small, stable passages for water infiltration. All of this improves water infiltration during rain storms resulting in more water going into the soil and less running off the surface. The organic matter and soil micro pores increase the amount of plant available water the soil can hold after a rainfall event. This allows plants to grow well longer between rains.

Nitrogen fixation and cycling

Pasture growth is highly dependent on available nitrogen. Nitrogen fixing legumes and their symbiotic bacteria are a critical component in the pasture ecosystem. Healthy and active nodules are identified by their red interior. This color is caused be the iron containing red leghemoglobin used as part of the nitrogen fixing system and is similar to the hemoglobin in blood. Different strains of rhizobium form symbiotic relations with different legume species. Legumes that form symbiotic relations with the same strain of rhizobia or actinomycetes are grouped together as cross-inoculation groups (Table 2). When planting legumes it is important to inoculate the seed with the bacterial strain that will become a symbiont with the legume being planted.

In pastures both leguminous forbs and trees and their associated bacteria provide nitrogen to the system (Table 3). Nitrogen fixed by the legume and bacteria is first supplied to the legume. Therefore, in a new seeding the grass at first does not get much nitrogen from the legume. The legumes take off nicely and sometimes outcompete the grasses. Legume nitrogen enters the soil through nitrogen rich root exudates, root and nodule death, livestock trampling, and dung and urine deposition. This nitrogen is made available to grasses and legumes as the organic matter is broken apart by the shredders and decomposed by the detritus feeders, bacteria, and fungus.

With time the legume roots meet with mycorrhizal fungus which attaches to the root. The mycorrhizal fungus also attach to grass roots. Then the fungus offers the clover extra phosphate in exchange for carbohydrate and nitrogen. The fungus provides part of the nitrogen to the grass from which it obtained the phosphate in exchange for carbohydrates. The fungus also obtains phosphate and trace minerals from the soil that it uses in this bartering system.

Accumulation of ammonia in the plant or high nitrate in the soil limits N fixation. Legumes preferentially use available soil N since there is a high energy cost to fixing N. Grasses are more competitive then legumes in taking up soil N due to their fibrous root systems. In soils that are high in nitrate grasses will have increased N uptake and be more competitive with the legume. This occurs in established grass-legume pastures as the organic matter builds up and a healthy microorganism community breaks the organic matter down releasing the nitrogen and converting it to nitrate. In these pastures grasses have a competitive advantage and the legumes may disappear. After a period of time the soil organic matter decreases and the available soil nitrate decreases causing the grasses to be less vigorous and the clovers come back in to the system. This is one of the causes of clover cycles in pastures.

<u>Management needed to help the system</u>

So what are the management practices needed to help the pasture ecosystem function at its best? I will define “best” as pasture ecosystems that captures solar energy, transfer that energy to ruminant animals that produces food for people in a socially, economically, and environmentally sustainable manner. These management practices are the ones that we have talked about again and again over the years.

1. Lime the soil to provide the pH that is optimum for plant, rhizobia, and other microbes the soil, a pH from 6.0-7.0 depending on the primary legume and its symbiont in the system.

2. Apply adequate but not excessive amounts of mineral or organic P and K fertilizers to the system. Organic fertilizers such as compost, biosolids, poultry litter, and other livestock manures provide trace minerals (Mo, Mn, Cu, Zn, B) as well as other macro minerals (N, S, Ca, Mg). Organic fertilizers also provide digestible carbon which is an energy source for decomposers. This will stimulate microbial growth and activity. Soil bacteria and fungus make nutrient more available to high plants but they have energy and other nutrients to work with.

3. When seeding legumes, make sure to inoculate the seed with the bacteria that will develop a symbiotic relation with the legume species being planted.

4. Manage the nutrients already on the farm. Grazing recycles nutrients in pastures. Manure management should recycle nutrients to the hay fields that the hay removed. Manure stimulates earthworm populations and activity as well as microbial populations and activity. Organic on-farm sources of nutrients include hay, other feed wastes, manure, and bedding. Where hay is fed back on meadows forage yields can be increased 2-fold during late spring droughts. This is due to higher soil organic matter holding additional plant available water. In wet years, yields are about 1.5 fold greater than where no hay was fed.

5. Graze pastures at the timing and intensity suitable for the forage species present. Grazing pastures to a 1- to 2-inch residual height during cool, moist weather benefits legumes and their rhizobia which fix nitrogen for all the organisms in the pasture system. Grazing too close during hot droughts can be detrimental to cool-season grasses and legume.

6. Close, rotational grazing of pastures in the fall helps develop tillers in the cool-season grasses and stolons on white clovers. It also reduces adult clover root curculio activity in pastures whose larvae are detrimental to legumes.

7. Rest pastures to get good cover before grazing to provide cover for night crawler earthworm. Night crawlers need adequate food and cover for reproduction especially in the cool moist weather of the spring and fall. Earthworms are like most animals they prefer legumes over grasses for forage.

8. When choosing fly control options consider their effect on dung beetles and other dung feeding insects and organisms. There are chemical and organic methods that do no harm to these beneficial organisms.

9. When choosing weed control options consider their effect on other plants and soil microorganisms. Co-grazing livestock such as sheep and goat that convert "weeds" to marketable animal products and manure has a positive effect on the pasture ecosystem.

Above ground we manage grasses, legumes, and forbs with animals to capture solar energy, convert solar energy into marketable livestock products, and to cycle nutrients so that our pasture-livestock system can be sustainable. The result of our management influences the soil environment and the organic matter available to feed macro- and microorganisms in the soil. This affects the soil's physical condition, availability of macro- and micronutrients to grasses, legumes and forbs, and plant available soil moisture. Understanding how our management affects the soil community can assist us in our management of the entire pasture ecosystem.

Further reading

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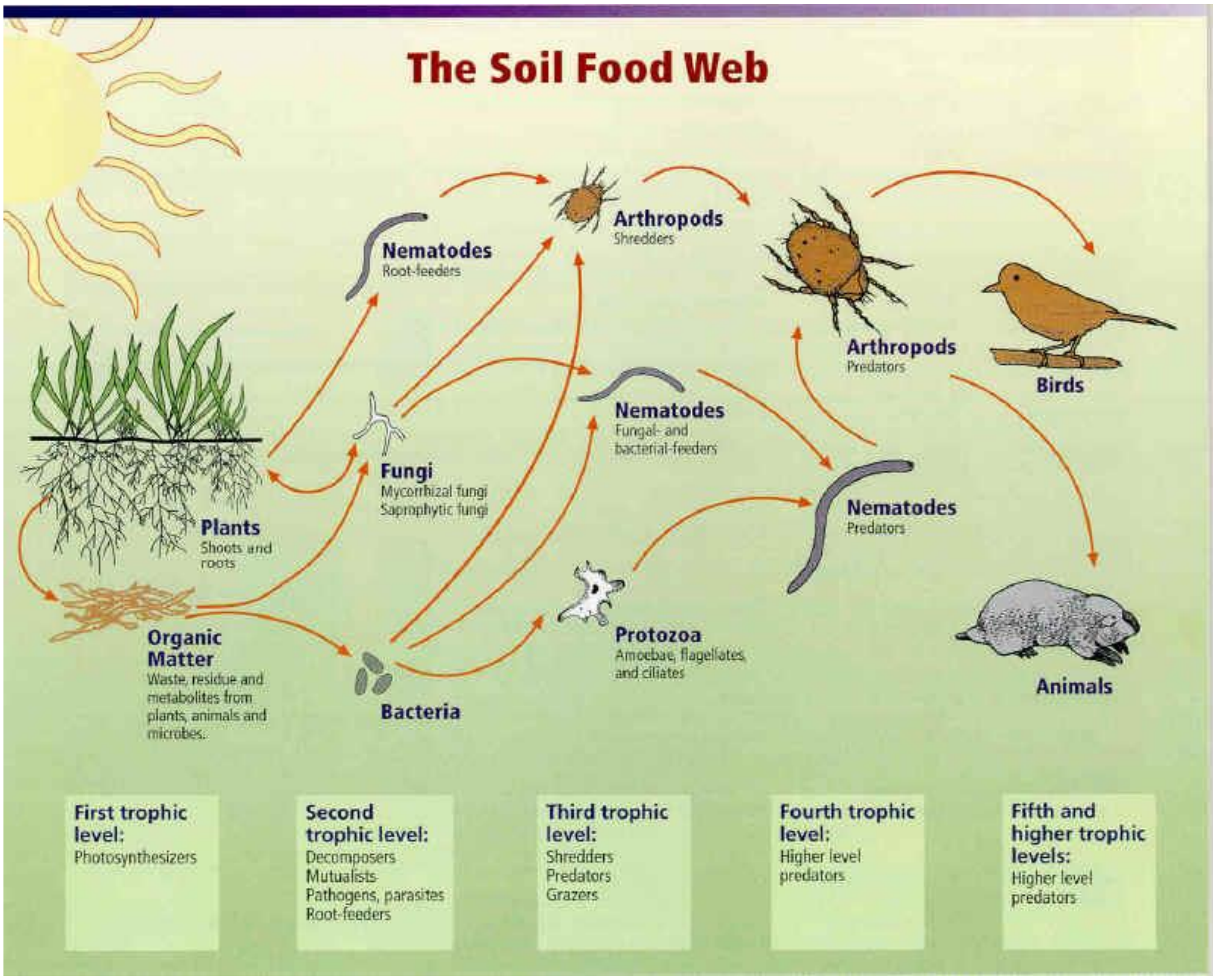
USDA/NRCS. The Soil Biology Web Site
http://soils.usda.gov/sqi/concepts/soil_biology/biology.html

Figure 1. The Soil Food Web.
(NRCS http://soils.usda.gov/sqi/concepts/soil_biology/soil_food_web.html)



This chart has not included earthworms, snails, slugs, and other soil dwelling organisms.

Figure 2. Generalized nutrient cycle for all mineral nutrients, carbon, and water; flow rates and concentrations differ for each nutrient.

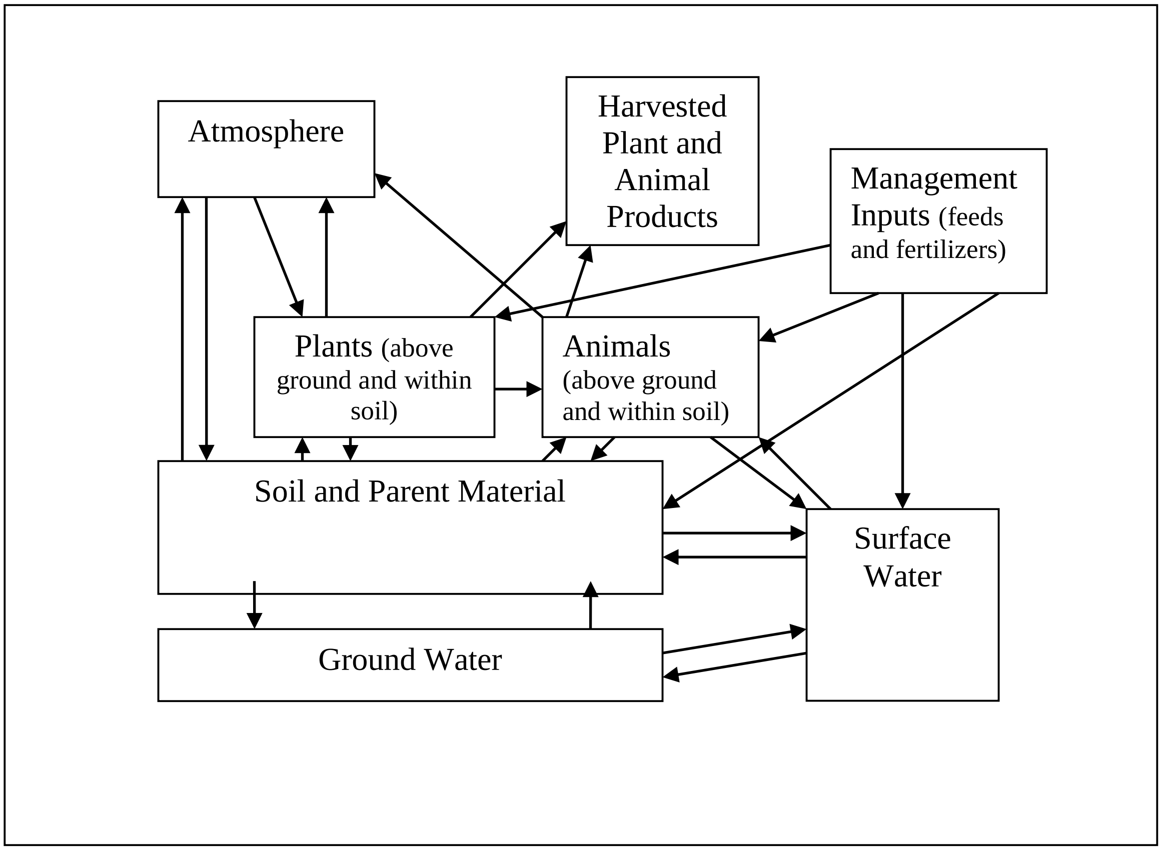


Table 1. Biomass of organisms above ground in the pasture and below ground within the pasture soil.

Organisms	Standing crop biomass lbs/a
Above ground	
1200 Dairy cow[1] or	587
1200 Beef cow[2]	450
Pasture[3]	2500
Below ground	
Pasture roots[4]	2500
Bacteria	2052
Actinomycetes	2052
Fungi	6244
Algae	219
Protozoa	80
Nematodes	62
Mites	65
Collembola	65
Earthworms	624
Other fauna	40

Adapted in part from Brady and Weil 2002.

1. Cow producing 40 lbs milk/day 180 days/acre, 50% of forage standing crop consumed, 5 rotations/year.
2. Cow weaning 600 lb calf 3 acres/year.
3. Cool-season grass-clover pasture, 10 inches tall at grazing.
4. Roots equal top growth at grazing.

Table 2. Cross inoculation groupings for different species of legumes.

Cross inoculation groups
Alfalfa, black medic, bur clover, red clover, sweet clover
Birdsfoot trefoil
Cowpeas, kudzu, lespedeza, partridge pea, peanut
Crotalaria
Crown vetch
Garden beans
Garden pea, hairy vetch, Canadian field pea, Austrian winter pea
Red clover, Ladino and other white clovers, alsike clover, crimson clover
Soybeans

Table 3. Annual rate of nitrogen fixation by different legume and none legume species and their associated symbiotic bacteria.

Host plant	Symbiotic bacteria	Nitrogen fixed/acre/year
Alfalfa	Rhizobium	150-300
Clover, white and red	Rhizobium	100-200
Locust tree	Rhizobium	75-200
Vetch and annual legumes	Rhizobium	75-150
Alders	Actinomycetes	50-185
Kudzu	Actinomycetes	100-140

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