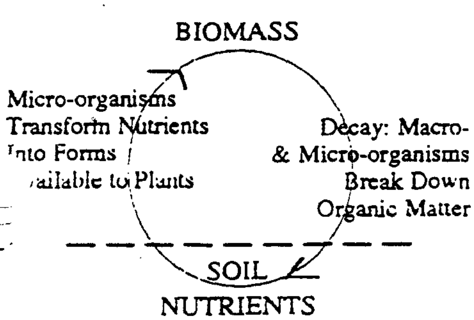
Soil Fertility

Lea Harrison

We need to understand how healthy soil functions, so that we can understand how to use it without depleting its fertility and how to restore degraded soil.

Soil is a mixture of organic and inorganic materials, containing a large variety of macro-organisms (eg. worms, ants, earwigs, termites, moles, gophers, etc.) and micro-organisms (eg. bacteria, fungi, algae, yeasts). Soil provides anchorage and support for plants, which extract water and nutrients from it. These nutrients are returned to the soil by the action of the soil organisms on dead or dying plant and animal material.



Fertility is a function of the efficiency of this recycling mechanism. The proportion of the nutrients tied up, either in the biomass, or in the soil at anytime, is a function of the climate. Soil organisms are inactive at low temperatures. Activity increases as the temperature increases (but ceases again at very high temperatures). Therefore, in temperate areas, where there is a wide difference between high summer and low winter temperatures, the activity of soil organisms slows or ceases over the winter. This causes a deep leaf litter buildup. In sub-tropical and tropical areas, where there is a high mean temperature throughout the year, the soil organisms are constantly active. Consequently, the leaf layer is thin, and the recycling of nutrients is relatively fast and continuous. In temperate areas the cycling of nutrients is relatively slow and periodic.

In temperate areas the largest portion of nutrients (90-95%) are in the soil at any one time. In tropical areas most of the nutrients (75-80%) are in the biomass. Therefore, to achieve and maintain fertility in temperate areas, we need to build up the nutrient content of the soil. In tropical areas we need to build up the biomass. That is, we need very different agricultural techniques for different climates. (The exporting of temperate agricultural techniques to tropical countries, has caused much ecological damage.)

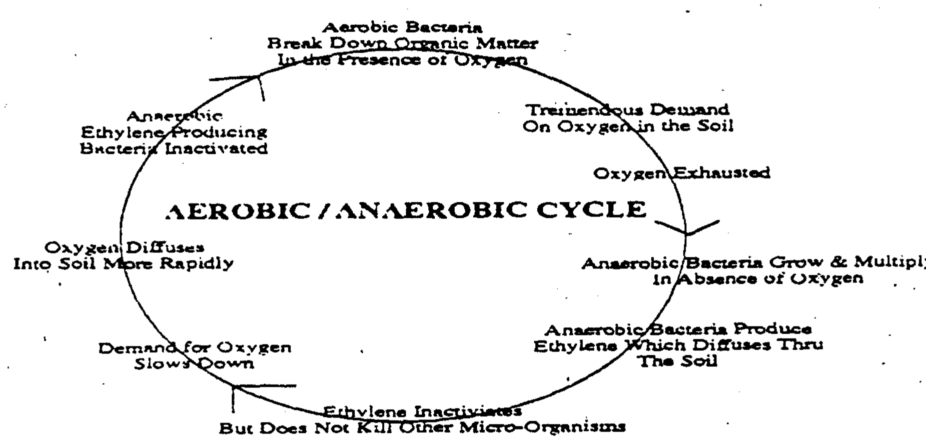
The difference in the rate of recycling of nutrients is responsible for the increase in growth rates and the increase in diversity of species, as you go from temperate to tropical areas.

Although soil organisms function at different rates in different climates, the way they function is the same. As fertility is dependent on the action of soil organisms recycling nutrients, we need to understand how this process works, so we can design optimal conditions for soil organism function into permaculture systems. That is, we need to design habitat and forage for healthy populations of soil organisms.

Healthy soil is loose, friable, and well aerated. It contains plenty of organic matter, about 5% in the sub-tropics, more in temperate areas. In addition, the top 15cm (6") contains about 20 tons of living matter per hectare (9 tons/acre). To find how this fertility is maintained, we need to look at undisturbed natural systems, either forests or grasslands, which have maintained themselves, plus the animal populations which live on them, over many centuries. (This is a good reason for preserving wilderness areas.)

The macro-organisms (worms, earwigs, ants, and other burrowing animals), take litter underneath the soil surface and release it in their feces. As they burrow, they make channels which help keep the soil aerated. We see an increase in the activity of these macro-organisms, particularly worms and ants in Australia, as soil fertility increases.

Micro-organisms are extremely numerous in healthy soil; eg. one gram of healthy topsoil contains about 1,000 million bacteria. All the micro-organisms that break down organic matter, thus recycling nutrients, are aerobic organisms. That is, they can only function in the presence of oxygen. All plant pathogens, which cause plant diseases, are also aerobic organisms. Even in well aerated soils, aerobic organisms use up oxygen faster than it diffuses into the soil. This creates, at any time, many microsites without oxygen, all through the soil. Anaerobic bacteria, which function only in the absence of oxygen, grow and multiply at these reduced microsites. They produce ethylene, which inactivates, but doesn't kill, aerobic micro-organisms. There is a complex rocking backwards and forwards between the functioning of aerobic and anaerobic bacteria, all the time, at microsites scattered all through the soil.



This was first recognized in 1970. It occurs in all soils.

Plant pathogens vary in their sensitivity to ethylene, but as a group they are much more sensitive to it than most other soil organisms, including the micro-organisms that break down organic matter. Therefore, when this delicate cycle is operating, the plant pathogens are kept quiet, but organic matter is still broken down.

As organic matter breaks down, essential plant nutrients are released. Different plants have different nutrient requirements, but they all need some of each to be healthy.

Major Nutrients

- N Nitrogen - Promotes plant growth. Key element in protein building and genetic coding.
- P Phosphorus - Helps in the transfer of energy from sunlight to the plant.
- K Potassium - Vital in control of diseases and pests because it thickens the cell walls of plants.

Secondary Nutrients

- Ca Calcium - For cell division, root tip growth, genetic coding, and neutralizing imbalances of other nutrients.
- Mg Magnesium- for chlorophyll.
- S Sulphur - For the production of flavor and odor compounds and protein.

Trace Elements

Fe - Iron, Zn - Zinc, Cu - Copper,
B - Boron, M - Manganese,
and about 40 others.

Nitrogen is produced from the breakdown of organic matter by micro-organisms, in the form of ammonium nitrogen. Nitrogen in the ammonium form is attached to the soil in such a way that it cannot be leached by water, or lost to the air by de-nitrification. Yet it is easily available to plants. If levels of ammonium nitrogen build up in the soil faster than it is being taken up by plants, specific soil bacteria turn it into nitrate nitrogen.

Nitrate nitrogen is very water soluble. Plants can use it easily, but it leaches out in rain, or de-nitrifies and is lost as gas. It acts like oxygen in stopping ethylene production. It interferes with the formation of anaerobic microsites. When there is no ethylene present, there is uncontrolled activity of aerobic bacteria. That is, there is an uncontrolled breakdown of organic matter. There is also uncontrolled growth and multiplication of plant pathogens.

This occurs in an undisturbed forest where there is an old, sick, or damaged tree. The tree is not using the ammonium nitrate produced to grow, as it normally would. Also, extra ammonium nitrogen is being produced from the breakdown of the extra organic matter, caused by the fall of damaged or dead leaves and branches and the dying back of roots. The excess ammonium nitrogen is turned into nitrate nitrogen. In nitrate form this excess nitrogen can be spread, by water, to other areas of the forest, where it can be taken up by other plants, or to the atmosphere as nitrogen gas.

At the sick tree site, the presence of nitrate nitrogen stops ethylene production. Therefore, the breakdown of organic matter continues unchecked, and conditions are favourable for plant pathogens to attack the living tree. Thus this old, sick, or damaged tree is broken down very quickly to stop it reproducing and to make room for new young productive trees to grow. ("In nature you are either perfect or you are replaced."—Smith) The nutrients from the tree's breakdown are used by the new young growth, or spread through the forest to where they are needed. The same system occurs in undisturbed grasslands. Plant disease and the presence of nitrate nitrogen in the soil are warning signs that something is out of balance, that here is an unhealthy plant that needs to be destroyed.

In undisturbed soil, there are around 15-20 parts per million of ammonium nitrogen and less than 2ppm of nitrate nitrogen. In disturbed soils (eg. cultivated croplands), there is no ammonium nitrogen and 20 to 200ppm of nitrate nitrogen.

magnesium) are displaced into solution and leached out. Most of the carbon in the organic matter goes into the air as carbon dioxide. All the energy released by the breakdown of organic matter is dissipated and wasted.

We plant a crop into this soil. It uses the remaining nitrogen. The soil tries to come back into balance, but so much of the energy from the organic matter has gone that there isn't enough to keep the organisms operating. The system is out of balance, as it was around the unhealthy forest tree. To produce a crop, the farmer must now spray the crop to kill the diseases and add fertilizer to replace the nutrients lost by ploughing. It is possible to produce the same situation in uncultivated soil, by the over-use of legumes (eg. in legume-dominant pasture).

Because there has always been a lot of nitrate nitrogen and no ammonium nitrogen in our crop lands, scientists, whose studies followed the plough, had assumed that that was what was needed. So, most commercial fertilizers have nitrogen in the nitrate form. Application of this keeps the system out of balance. Organic gardeners, who apply fertilizer with nitrogen in the ammonium form, usually combined with organic matter, can get the system back into balance at this point. However, overuse of ammonium nitrogen type fertilizer will keep the system out of balance.

Nitrogen Values	AMMONIUM Nitrogen	NITRATE Nitrogen
UNDISTURBED SOILS	15-20 p.p.million	< 2 p.p.million
DISTURBED SOILS (Cultivated)	--	20-200 p.p.m.

Therefore, the cultivated soil is way out of balance, the crops are unhealthy, and they will be attacked by disease.

In present Western agriculture, the soil is generally ploughed or cultivated. This breaks up the soil and aerates it very quickly. Microsites where ethylene is being produced, are flooded with oxygen. Therefore, no ethylene is produced. Uncontrolled breakdown of organic matter occurs. A lot of ammonium nitrogen is produced, but there are no plants in the cultivated soil to use it. Therefore, nitrifying bacteria turn it into nitrate nitrogen, so it can be shifted to where there are plants to use it. During this process, the soil becomes more acid and other nutrients (eg. calcium, potash,

We need to go back to the undisturbed soil system to see how nutrients, other than nitrogen, are made available to plants. There are adequate reserves of these nutrients in healthy soils, but they are held in insoluble forms to stop them being lost by leaching. Plants can only take them up in a soluble form. The plant changes the environment around it to make nutrients available.

As the root pushes through the soil, it squeezes the soil, and a water film (the rhizosphere) collects around the edge of the root. The roots leak 2-10% of the total carbon the plant produces through photosynthesis into the rhizosphere. The breakdown of organic matter by micro-organisms requires a lot of energy to get started. This energy is available from the carbon that the plant roots have leaked into the rhizosphere, so that is where the micro-organisms collect.

Iron is present in all healthy soils (2-12% of soil weight) as minute crystals of ferric iron. Plant nutrients (eg. phosphate, sulphate, and trace elements) stick tightly to the highly charged and relatively large surface area of the ferric iron crystals. In this state they are immobile and cannot be leached, but are unavailable to plants. As microsites where there is no oxygen form, these crystals break down from ferric to ferrous iron. The bound nutrients are released and can be taken up by the plants. High concentrations of highly mobile ferrous iron ions are now in solution at the microsite.

Other essential plant nutrients (eg. calcium, potassium, magnesium, ammonium) are held on the surfaces of the clay particles and organic matter particles. When high concentrations of ferrous iron are present, the ferrous iron displaces these nutrients into the soil solution, where they can be taken up by the plant roots. The conditions necessary for this mobilization of nutrients are identical with those required for ethylene production: the absence of oxygen and nitrate nitrogen.

Since the greatest concentration of micro-organisms are in the rhizosphere, this is where anaerobic microsites are most likely to form. Thus, the nutrients are mobilized exactly where they are needed by the plants. They can't be lost by leaching, because as soon as they get to the edge of the microsite, the ferrous iron re-oxidizes to ferric and the nutrients are rebound to the iron crystals, clay particles and particles of organic matter. Therefore, where ethylene production can't occur, these nutrients are locked up in a state unavailable to plants.

Ferrous iron is a specific trigger to ethylene production. It reacts with a precursor of ethylene, present in the soil from the breakdown of mature leaf litter, and a reaction occurs that results in the release of ethylene. In undisturbed plant communities, mature leaves are the bulk of the litter layer. In Western agriculture, most of these leaves are removed by harvesting, grazing or burning. Therefore, agricultural soils tend to be deficient in ethylene precursor. Different plant species accumulate markedly different amounts of precursor in their leaves. For example, rice, chrysanthemum, avocado, bullrush, and *Pinus radiata* all have high levels. Dolichos, paspalum, lucerne (alfalfa), and bracken fern have low levels. This is important when selecting plant species to use.

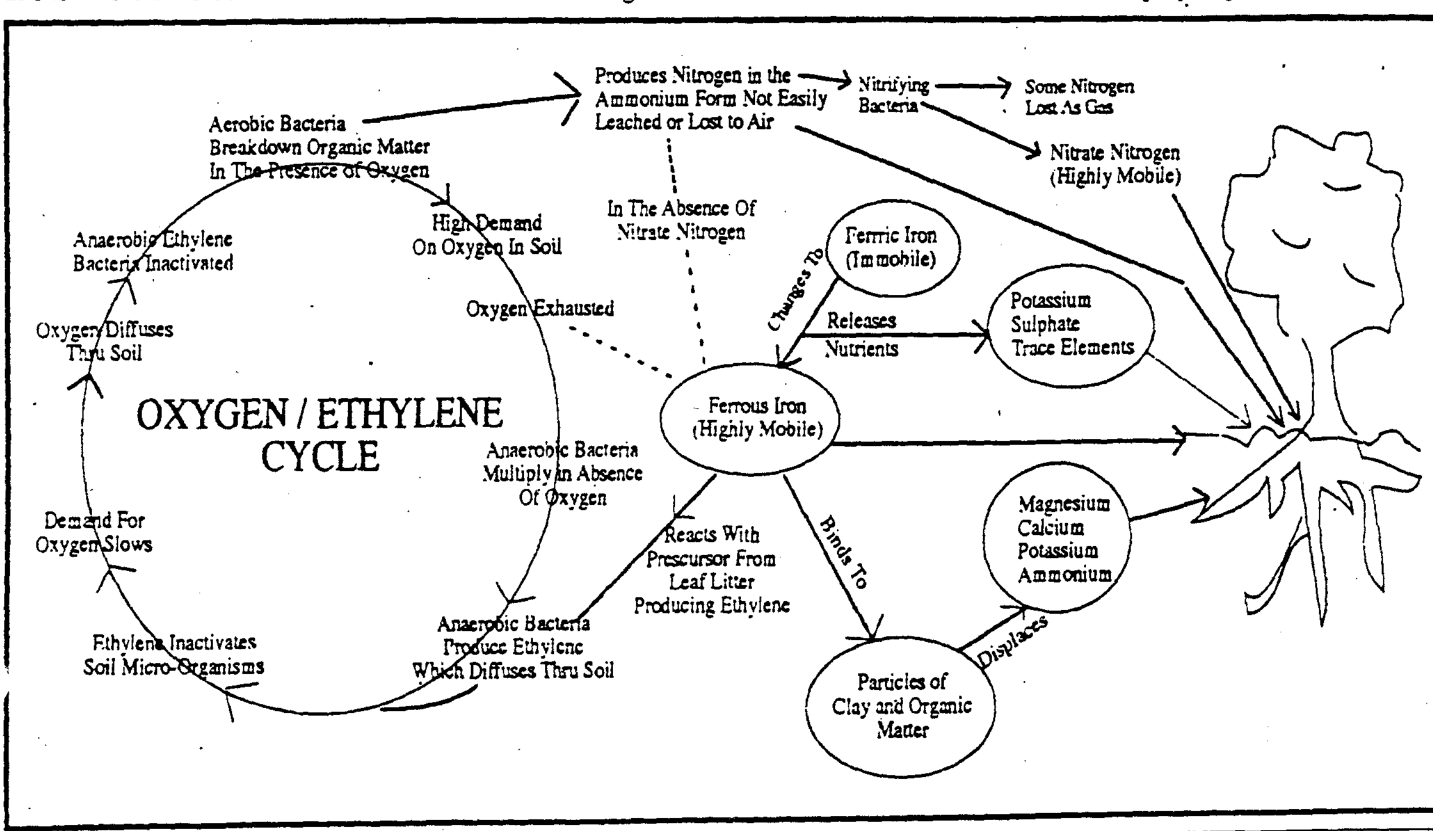
Our present agricultural methods give short-term increases in production at the expense of long-term stability. Excessive use of nitrogenous fertilizer, excessive removal of plants by cultivation, clearing, burning, and overgrazing, plus overuse of legumes, may give us a short-term increase in crop yield. The long-term results are:

- The total energy cost of our crops increases. Somewhere between 5 and 50 energy units are put into the soil for each one we take from it.
- The fertility of the soil decreases, because of loss of nutrients and organic matter, leading to increasing acidity or alkalinity, salting, toxicity, erosion, and desertification.
- The nutritive value of the crop decreases.
- The resistance of the crop to disease decreases.
- The level of toxic chemicals contained by the soil, the crop, the farmer, and the consumer increases.
- Our health and resistance to disease decreases.
- Our visibility as a species decreases.

"In nature you are either perfect or you are replaced." This is the state of our present agriculture. It is not sustainable.

The aim of agriculture is to trap energy from the sun, through plants, to give food and fuel to us and food for our animals.

The breaking of carbon-to-carbon bonds in sugar or starch, manufactured by plants, gives us energy in a form we can use. We say we must cultivate, fertilize, and spray to produce food, but



the air and soil contain everything plants need. Each teaspoon of soil contains hundreds of thousands of micro-organisms that will make nutrients available to plants: as long as we do not interfere, but let the system operate.

ENERGY + H_2O + CO_2 + PLANT NUTRIENTS → (Chlorophyll As A Catalyst) → SUGAR or STARCH

from Sunshine | Water | from Air | & Trace Elements | $C \neq C$

What can we do then to help maintain soil fertility and to increase the fertility of degraded soils?

Firstly, it is essential that organic matter be returned continually to the soil. The best organic matter is from mature plants and it is better to return it to the surface of the soil than to turn it into the soil. Crop residues should not be burnt. Pasture should not be overgrazed and should be left fallow periodically. Cultivated plants should have mulch or cover crops around them. Some cover crops should be selected for high levels of ethylene precursor. In this way, nutrients will be recycled, microbial activity will be stimulated, and adequate levels of ethylene precursor will be provided.

Where it is necessary to cultivate, to aerate compacted soils, minimum tillage techniques should be used. Don't dig, don't plough, cut weeds rather than pull them out. Thus plants are kept growing on the soil all the time and the soil is disturbed as little as possible.

When we need to apply fertilizer to increase the fertility of poor soil or to establish young trees, we should apply nitrogenous fertilizer in the form of ammonium. The only way to stop nitrification of any form of nitrogen, whether it is being supplied naturally from organic matter or legumes, or from a bag, is if it is being taken up by the plant roots as fast as it is being supplied, or if it is locked up by micro-organisms and released slowly as they die. Therefore, fertilizer should be applied at times of high plant demand. Several small applications are better than one or two heavy ones. When fertilizer is applied, we can add mature plant material; eg. dried grass stalks or wheat straw which has a high carbon, low nitrogen content. The micro-organisms use the carbon and therefore the nitrogen, locking it up in their own bodies from which it is slowly released over time.

Don't overuse legumes in your system. Copy the natural balance of legumes in the area; eg. in the sub-tropics there are few legumes in the herb layer, a lot in the pioneer stage, then relatively few in the climax stage.

Always mix some natives among exotic species to keep the native soil organisms healthy.

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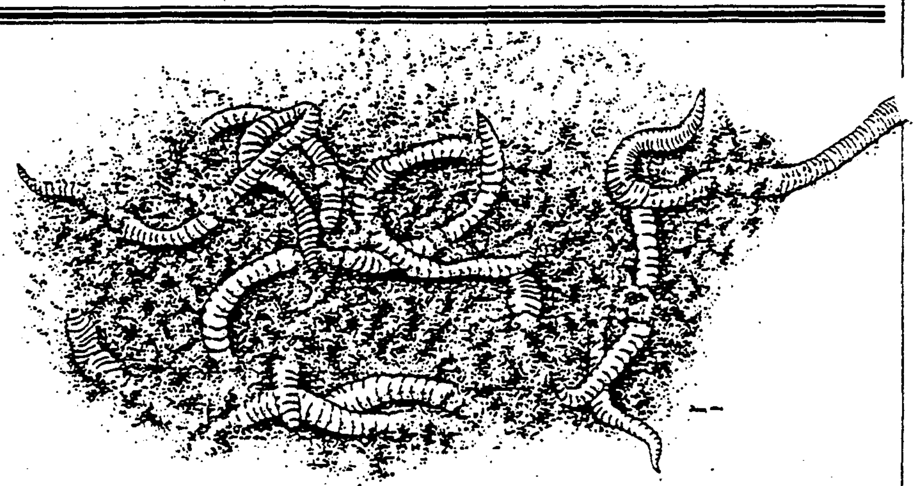

Earthworms in Agroecosystems

Cathy Baldwin

Earthworms are one of the grower's greatest allies: by decomposing organic matter, generating nutrient-rich casts and opening channels in the soil, earthworms improve soil fertility and structure. Yet many farming practices, including frequent tillage and the use of chemical fertilizers and pesticides, have detrimental effects on earthworms and their habitats.

Earthworm Types and Habitats

According to Matthew Werner, a soil ecologist with the Agroecology Program, there may be several hundred earthworm species in North America, but only a dozen or so species in the family *Lumbricidae*, introduced from Europe, seem to be important in agricultural soils. These can be classified into three groups based on their morphology (size and shape) and habitat.

Epigeic species reach an inch or two in length and inhabit the organic matter lying on the soil surface, where they eat fallen leaves and other undecomposed litter. A familiar epigeic species is *Eisenia foetida*, the redworm or manure worm, which is used in vermicomposting. Vermicomposting is the process