CHAPTER 26

SOIL EVOLUTION; ECOLOGY; AND FERTILITY

26. 1. INTRODUCTION

26. 1. 1. The Importance of Soil

Soil is the basis of almost all agriculture. **Hydroponics**, or soil-less agriculture, is one exception. Another is our southern neighboring atoll islands' use of **compost beds** *(described below)*. Soil is essential to the beautiful plant life of our islands. We could not grow much if we lived on an island of solid rock with no soil at all.

One reason for the great wealth of the United States of America is that it has much of the world's best soil.

Most island crops require soil, as do our forests and grasslands. One example of an exception is *Vanilla*, a tropical epiphyte sometimes harvested for its flavorful beans.

The kinds of soils we have can limit what we can grow. In fact, to a very great extent, the characteristics of our soils limit what we can do with our land in general.

Unfortunately, careless use of soils can easily damage them. This reduces their usefulness for producing either foods or forests, or both. When we are on an island that has only beach sand, we may be able to grow little more than coconuts and perhaps a few other strand plants for medicinal use.

Good soil, **topsoil**, is so valuable that countries have fought wars to obtain some other country's soil. This was usually initiated after the first country had already ruined its own soil resources. One reason for the great wealth of the United States of America is that it has much of the world's best soil.

Vanilla, a tropical epiphyte, is one of the few crops which does not require soil.

26. 2. THE GENESIS AND EVOLUTION OF OUR ISLAND'S SOIL

26. 2. 1. Soil Genesis and Soil Evolution Defined

Genesis (like the name of the beginning chapter of the Bible) refers to the making of something in the beginning. The word **evolution** suggests progress from something simple to something complex. Soil is certainly more complex than bare rock.

26. 2. 2. The Difference Between "Soil" and "Dirt"

To begin at the beginning, *soil* is not *dirt* until it is out of place, like on one's face or on the kitchen table. Dirt is worthless and a problem. Soil, on the other hand, is extremely valuable.

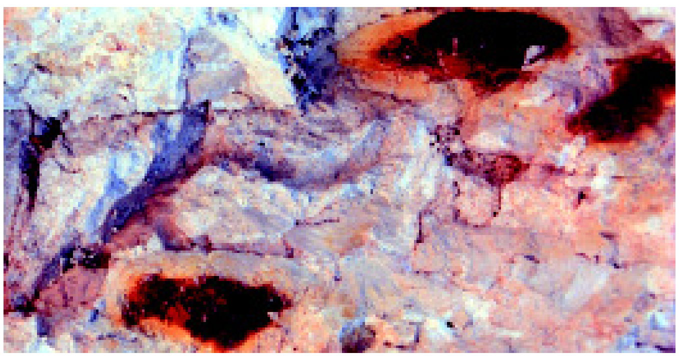
26. 2. 3. Soil Defined

A mini-description of a soil might be **unconsolidated** (loose), **heterogeneous** (made of several parts) material that supports plants in nature.

Another way to say this is that soil is a matrix or medium that supports plant life. This idea of a medium that holds a plant up is only the beginning of our story, but it is enough to get us started. We will find that soils have quite a lot of fascinating qualities.

26. 2. 4. Soil Components

Four things that make up soil are rock that has weathered, air, organic matter, and moisture. Weathered rock by itself is just dust or sand, with, perhaps, some air spaces in it. Small bits of rock and air alone are not *soil*.



Locally, our non-soil, rock lower elements are either limestone bedrock or a soft-bedrock volcanic material called saprolite.

We can further divide these into two distinct parts, **solids** and **voids**. The weathered rock (called **minerals**) and the organic matter together make up the *solids*. Air and the water fill the pore space between the solids. This pore space is called the *voids*.

Technically, a soil is a natural body extending downwards from the surface to non-soil. Locally, our non-soil, rock lower elements are either limestone bedrock or a soft-bedrock volcanic material sometimes called **saprolite**.

26. 2. 5. "Organic Matter" and "Humus" Defined

Microscopic living things like bacteria, and threads of fungus (molds), are parts of our soils, as are larger things such as roots, insects, and worms. We call matter that is alive, or was alive, **organic matter**. Dead plants and animals do not completely rot away under many conditions and instead turn into organic soil materials.

Humus is dead organic matter that has decayed to a great extent, until it is a dark, crumbly material in our soil. Humus is the most decomposed form of organic matter. Humus coats the outside of mineral particles (sand, silt, and clay) and is usually found at the surface layer (topsoil). The topsoil is also our most fertile soil layer. Most plant nutrients are here. Humus, and the living things in the soil, combined, make up the organic parts of the soil.

Organic matter absorbs water and dissolved plant nutrients. This *held* water is then available for plant use. Organic matter helps keep nutrients and loose soils from washing away, while keeping other soils from getting too "hard" and water-repellent.

Organic matter makes **heavy** (*clayey*) soils seem lighter by making them easier to crumble, and it makes **light-sandy** soils seem a little heavier by holding the mineral material together in pea-sized **crumb-like aggregates** (much like cookie crumbs).

Heavy soils are those with a majority of clay-sized particles. Sandy soils are those with a majority of sand-sized particles. In the CNMI, the limestone and volcanic rock particles chemically bind organic matter to themselves forming these all important *crumbs*. (We discuss soil particle size in more detail below).

Adding compost improves soil **tilth**. A soil's *tilth* is the quality which the soil has that help seeds within it to germinate.

26. 2. 6. Qualities of a Good Soil
A very good soil is a **loam** that makes crumbs. Soil that is bare too much of the time has less organic material and cannot make crumbs.

It is a shame that, in most cultivated places in the CNMI, heavy soils no longer make crumbs, and become very solid and hard when dry. Adding or retaining more organic matter can greatly help such heavy soils.

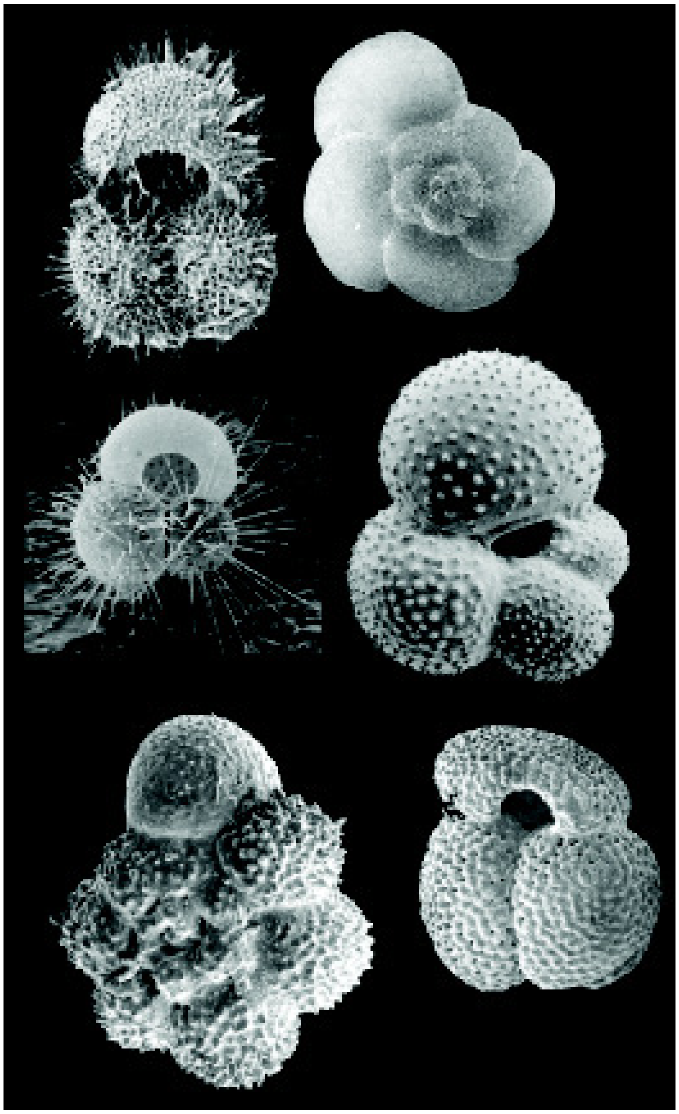
26. 2. 7. Soil Moisture
Moisture by itself is just water; water must be present with various minerals dissolved in it. Plants use the dissolved minerals of a soil's water in all of their growth and metabolic processes.

26. 2. 8. Parent Materials and Soil Life
Some sands and volcanic materials are rock already broken into tiny pieces. However, if they are still **homogeneous** (all one thing), they are still **parent material,** until they become heterogeneous (mixed) with some organic material and water with minerals.

Properly combining all of these components makes soil, but not always a very good soil. Good soils have the capability to support plant life. For the most part, natural forces do the major work of combining our soil-making components. Such natural forces include actions by mechanical and chemical weathering, plant roots, and soil-dwelling animals.

Although we usually think of soil as being made of minerals, we should think of natural soil as being *alive*. This is because, like the sea, there are so many living things in it.

26. 2. 9. Predominantly Limestone-derived Soils
Limestone means coral rock and rocks made of materials that are like coral. It is the parent material on coral islands. As we described earlier (in Chapter 13), the bone-like and shell-like skeletons of coral animals and the bodies of coralline algae (green and red algae that make chalky material) form coral reefs.



Foraminifera, among other organisms, are a contributor to the calcium carbonate which comprises coral limestone.

This bone-like material is mostly calcium carbonate ($CaCO_3$) from coral animals, **foraminifera** (protozoa), coralline red algae, and coralline green algae. These have been crushed together and have stuck together to make limestone.

Coral islands made of limestone originate from coral reefs. These have been pushed out of the water by huge geologic events. Often there is an old volcano under the coral island.

On certain of the southernmost Mariana Islands, this volcanic rock comes to the surface in some places. As we've learned, our northernmost islands are entirely volcanic.

26. 2. 10. Soil Weathering

Weather, plants, and animals all help to make soil. When local rocks, either limestone or volcanic, are exposed to daytime sunlight, they heat up and **expand** (get a little larger). Then, at night or when it rains, these rocks **contract** (shrink).

Rock weathered by rain. A slightly acidic rain is important because it dissolves rock minerals into water.

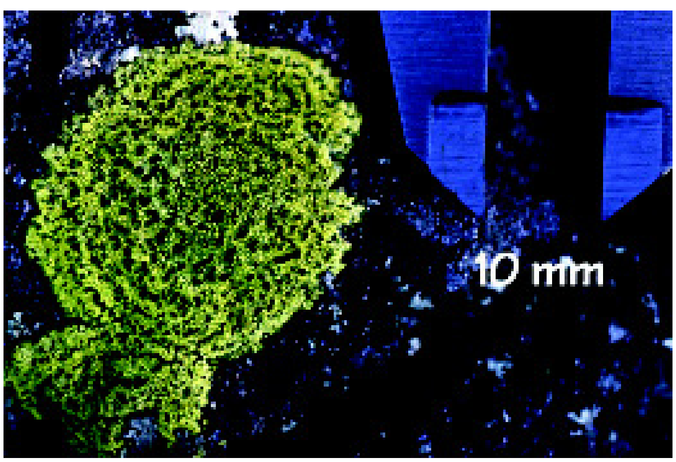
This expansion and contraction causes rocks to crack or flake. Windblown sand, sand carried in running water, and sand driven against the rock by waves at the island's edge also break little pieces off the rock, making more sand.

Rainwater soaks up the carbon dioxide that people and animals exhale. Rain also soaks up sulfur compounds from volcanoes, to become **acidic** (have a chemical reaction something like vinegar).

This is not the strongly acid rain that results from too much industrial sulfur, but it is acidic enough to slowly dissolve rock, especially coral rock. This slightly acidic rain is also important because it dissolves rock minerals into water. Plants need these minerals for growth.

26. 2. 11. Plant Growth on Bare Rock (Lichen and Mosses)

On bare rock, tiny green or black crust-like plants called **lichens** also work to dissolve the rock. They contribute their dead parts and help hold little bits of sand, dust, and bird droppings in place so that very thin layers of soil may develop on bare rock.



On bare rock, tiny green or black crust-like plants called lichens also work to dissolve the rock.

Slightly larger simple plants, like mosses, continue this process, holding still more of the thin new layer of soil. This helps prevent it from washing or blowing away. Eventually, enough material collects until it becomes thin seed beds for grasses, sedges, ferns, and small herbs.

All of these plants may have roots that grow into tiny cracks and then go on growing with enough force to further crack the rock. They will also hold more organic matter in place and will themselves become part of this new soil when they die.

Eventually, larger woody plants and small trees may start growing, and their roots will hold much more soil in place. They also crack the subsurface rock a lot more.

26. 2. 12. Other Soil Genesis Methods

In low places, soil may develop from materials washing down from above and collecting as the water slows down, or pools. Animals digging and scratching also scrape tiny flakes off the rock.

Oxygen in the air **oxidizes** (burns or rusts, in this case, slowly for months, years, or centuries) volcanic rock to make it *softer and looser* (unconsolidated). Oxidation helps to form the smallest-sized soil particles, the *clays*. Water may, under a variety of conditions, dissolve minerals from rocks.

One may wonder why many of our soils have a reddish hue. This is the result of the oxidizing of the soil's iron component from our volcanic rocks. Even our deep calcium-rich soils, evolved from the weathering of limestone, can be quite reddish from *iron contaminants* oxidizing within them.

Then, these iron chemicals may either **precipitate** (turn back into solid stuff), wash away, or remain in the soil where they become plant food (nutrients).

26. 2. 13. Soil Formation Rates and Erosion

Natural soil formation processes may take a very long time—more than several lifetimes, even tens of thousands of years, as on sloping limestone here in the CNMI—to make an inch (2.53 centimeters) of soil.

Under ideal conditions, on the other hand, an accumulation rate of soil can be as high as one inch per one hundred years.

In places where the rain beats down or the water runs steeply down hill, the soil may **erode** (be carried away by wind and, especially, water). Soil can erode almost as fast as it is made, especially if it forms on coral rock.

For the most part, wind erosion is not as big an erosion problem here as it is elsewhere. Water erosion, however, is a very serious local concern. Iron and aluminum oxides form aggregates that are resistant to the wind, especially at the surface where organic matter is present which helps bind these aggregates. Disturbing a soil's surface can easily disrupt this by removing the necessary organic cover.

If untouched by humans, the quantity of soil may indicate how old an island is and the relationship to the parent materials from which the soil is formed. If humans are careless, there will be much less soil than there should be.

The red color of our soil is the result of the oxidizing of the soil's iron component from our volcanic rocks.

26. 3. SOIL PARTICLES

26. 3. 1. Soil Particle Sizes and Soil Texture

Soils are composed of several particle size categories. Soil particles are little pieces of mineral which are classified into three sizes.

Sand is the largest-sized particle, and is up to about two millimeters in diameter. **Silt** is middle sized, and ranges from being visible with a hand lens to barely visible with a microscopic. **Clay** is so small that one needs an electron microscope to see separate particles.

Soil texture is how the soil feels, and what it is like to use. It is most often judged by hand texturing in a field. Laboratory tests can be done as well.

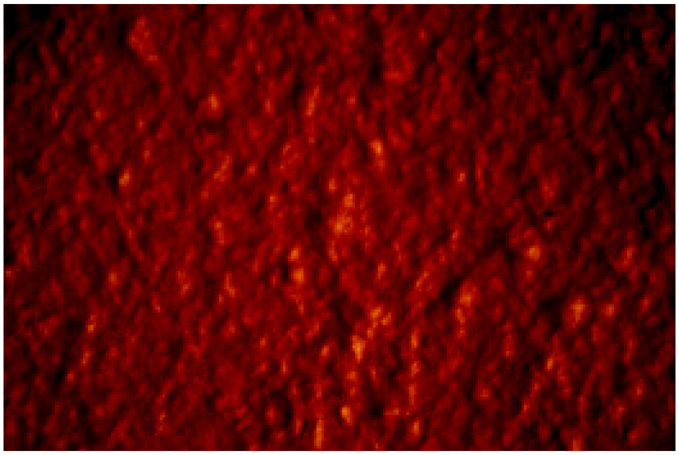
In places where the rain beats down, or the water runs steeply down hill, the soil may erode (be carried away by wind and especially water).

Soil Particle Sizes

Sand	= .05 to 2mm (anything bigger is gravel, pebbles, or even boulders)
Silt	= .002 to .049mm
Clay	= less than .002mm

A sample of *pure sand* feels gritty; *pure silt* feels like flour, and *pure clay* feels very sticky when moist.

Soil texture is determined by the relative percentages of these three particle sizes: sand, silt, and clay. A good soil is a mixture of all three sizes, along with organic matter.



Clay, at less than .002mm, will feel sticky...

26. 3. 2. A Clayey Texture

A clayey texture means the soil feels sticky, having much clay in it. It dries very slowly and may then dry out very hard and crack.

However, when it gets wet, it holds so much water that there may not be any air for the roots and other living things that need oxygen.

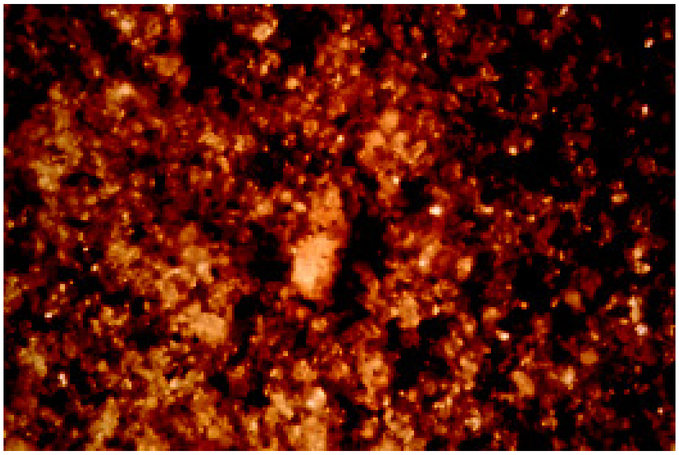
Often water soaks into it so slowly that most rainfall runs off it and is lost. This happens whenever there is not a crumbly structure at the soil's surface to allow rainwater to enter, and when there is not a good subsoil beneath it to drain away excess water.

26. 3. 3. A Loamy Texture

Agriculturists refer to **loam** as a *friable* mixture of silt, sand, and clay. A loamy texture describes soil that feels similar to clay, but crumbles like cake when it isn't moist. It usually has much silt and only a little clay, so it is not as sticky as clay.

It is the silt fraction of a soil that is like *rock flour*. Silt is what makes one's hands *dirty*. Loam is just right for a garden soil or a potting mixture. Rain usually soaks into it more easily if it is well-structured.

Loam neither dries out too fast, nor does it tend to stay too wet. Depending on which soil particle fraction is greatest, soils get referred to as *sandy loam*, *silt loam*, and *clay loam*.



Silt, at .002 to .049mm, will feel like flour...

26. 3. 4. A Sandy Texture

A **sandy** texture is very loose. It is made of easily seen small rock particles. It has almost no clay or silt in it. Water tends to run right through it. Sandy soils blow around easily and any dissolved minerals tend to disappear quickly.

26. 3. 5. Saturated Soil

In some low spots, such as under and around lakes, much organic material may accumulate in the soil. These areas are referred to as **hydric soils** and form the base for rooted wetland plants. Wetland plants have adapted to survive in saturated soils.

26. 3. 6. Clay Particles, Organic Matter, and Soil Salts

Clay particles are usually **crystalline** (made of crystals), and as mentioned, are the tiniest of all soil particles.

The surfaces of microscopic clays and of their crystalline layers often have **charged** (like having tiny bits of static electricity) places. The surfaces of partially decayed organic material also have these charged places.

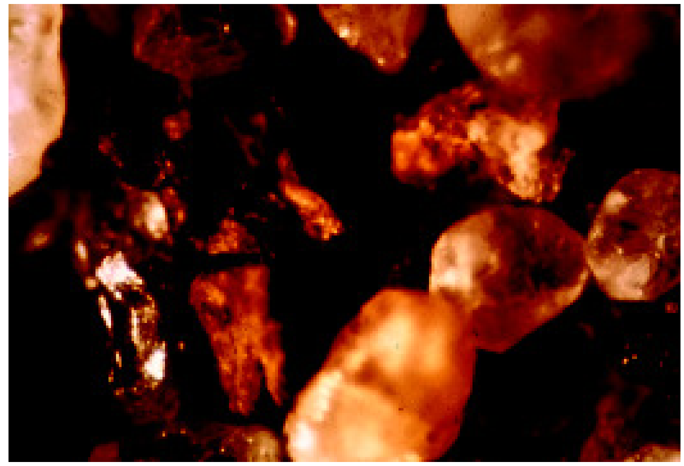
These *charged places* hold dissolved salts, including both sodium chloride (sea salt) and plant nutrients (which are also salts). Thus, clay particles hold plant food from washing away too quickly in our high rainfall environment.

The clay's and organic matter's holding of the nutrient salts allows them to be stored within our soils. They are then made available to plant roots when they are absorbed as part of the *soil solution*.

Most of our soils are very high in clay, but through weathering, the clays have less potential to hold these nutrient salts due to the very high number of iron and aluminum oxides present.

Unfortunately, sea salt (like *table salt*) is generally bad for crops and displaces (takes the place of) good fertilizer salts previously stuck to the clay and organic part of the soil.

For this reason, try not to water plants with salty water. The salt, even from water that is a lot less salty than sea water, can collect in a soil and ruin it. Collect rainwater instead and use it to water your plants.



while sand, at .05 to 2mm, will feel gritty.

26. 4. SOIL FERTILITY AND GOOD FARMING PRACTICES

26. 4. 1. The Terms "Soil Fertility" and "Fertilizers" Defined

Soil fertility is the ability to bring forth good things. A good soil for gardening and farming should have certain qualities, along with a good tilth.

One of these qualities is stored plant foods. Plant nutrients (foods) are called **fertilizer** if a farmer or gardener adds them. As the word fertilizer implies, it should increase fertility.

A truly fertile soil has all the plant foods necessary so that plants can grow. Plant foods must be **soluble** (able to dissolve in water) so they can get into the plant.

Even sandy and clayey soils can have favorable conditions for plant growth if enough organic matter is present in the soil to create a loose structure, a high water and nutrient holding ability, and an adequate aeration flow.

Loam is a friable mixture of silt, sand, and clay. A loamy texture describes soil that feels similar to clay, but crumbles like cake when the soil isn't moist.

26. 4. 2. The Three Most Important Plant Nutrients

The most important plant foods are soluble forms of **phosphorous**, **potassium**, and **nitrogen**. The first two come mostly from rock. (Phosphorous is sometimes mined as phosphate rock, often originating from bird 'guano' deposits.)

The last must be *fixed* (combined with oxygen or hydrogen) from nitrogen gas in the air by certain living things before it can be used by plants.

These are the three most important plant foods because plants need them in relatively large quantities. Usually there is not enough of them in the soil and gardeners and farmers have to add more as fertilizer in the form of commercial fertilizer or compost.

26. 4. 3. Sulfur and Trace Elements

Usually there is enough **sulfur** (a yellow element from volcanoes), even though plants need quite a lot of it. Often, sulfur is also incidentally added as part of other fertilizer mixtures, such as superphosphate.

About twenty other mineral elements are also needed by plants. These are called **trace elements** because only a tiny bit is needed.

Sulfur, an important mineral for plants, is added as part of fertilizer mixtures such as superphosphate.

Sometimes the soil needs some of these and small amounts must be added. Good soil should hold all these plant nutrients from being washed away by rain. Good soil supports healthy plant growth. This vegetation, in turn, helps hold soil in place where the land surface is sloping, even if this slope is ever so slight.

26. 4. 4. Air Spaces

Unless farm or garden soil is going to be used for growing flooded crops (taro, rice, KANGKUN, etc.), the soil should have enough air spaces in it to allow the roots to breathe.

Machinery that is too heavy packs soil down, crushing the air spaces out of it. This crushing of the air spaces out of the soil is called **compaction**. Resistance to such compaction is called *bearing strength* and many of our soils have low bearing strength, meaning they are easily compacted.

Compacting also makes it more difficult for water to soak into the soil. A fifteen horsepower tractor is appropriate on our islands; a tractor bigger than twenty-five horsepower weighs too much and is too big for CNMI soils.

Compaction can also greatly increase run off on sloping lands.

26. 4. 5. Puddling and the Need to Avoid Plowing Wet Soils

Plowing, disking or similarly working wet soils makes slick, shiny surfaces. It also destroys most of the air spaces. Further, it alters the natural *crumb* structure in the plow layer. The sheets of crystals that make up clay particles become jammed together. When this happens, soil scientists call such clay particles, "damaged".

Damaged clay does not hold plant foods well. This destructive process is called **puddling**. It is one of the worst things that can happen to a soil. Only a few *flooded crops* like lowland rice and KANGKUN can grow well in puddled soils.

If we puddle a soil today, and if, say, we could come back 200 years from now, we might still be able to see plants growing more poorly on it than those growing on an unpuddled soil beside it. Even most weeds cannot grow well in puddled soils.

Puddling can reduce crop yields for more than a hundred years. This is because puddled soils severely limit plant root penetration. Adding compost or green manure would speed up the recovery of a soil's damaged clays. To avoid the puddling problem in the first place, never plow wet soil.

26. 4. 6. Soil Acidity

Good soils must not be too **acid** (like vinegar, which is acid) or too **alkaline** (like washing soda, which is *alkaline*, the chemical opposite of acid) or some elements will not be soluble. Another word for alkaline is **basic**. A measurement scale for acidity/alkalinity in water or wet things is **pH.**

Chemists use a special numerical scale to measure pH. Soil with a pH of 0 is the most acid possible and a pH of 14 is the most alkaline possible.

If a soil is too acid or too basic, some of the necessary plant foods (nutrients) will not stay soluble enough, and the farmer will have to keep adding them to grow much of anything.

The ideal soil is pH 6.8. Depending on the crop grown, a garden soil with a pH much higher than 7.5 or lower than 6 is likely to cause problems.

Limestone is slightly basic and may be ground and added to soils that are too acid to make them closer to **neutral** (halfway between acid and alkaline, pH 7).

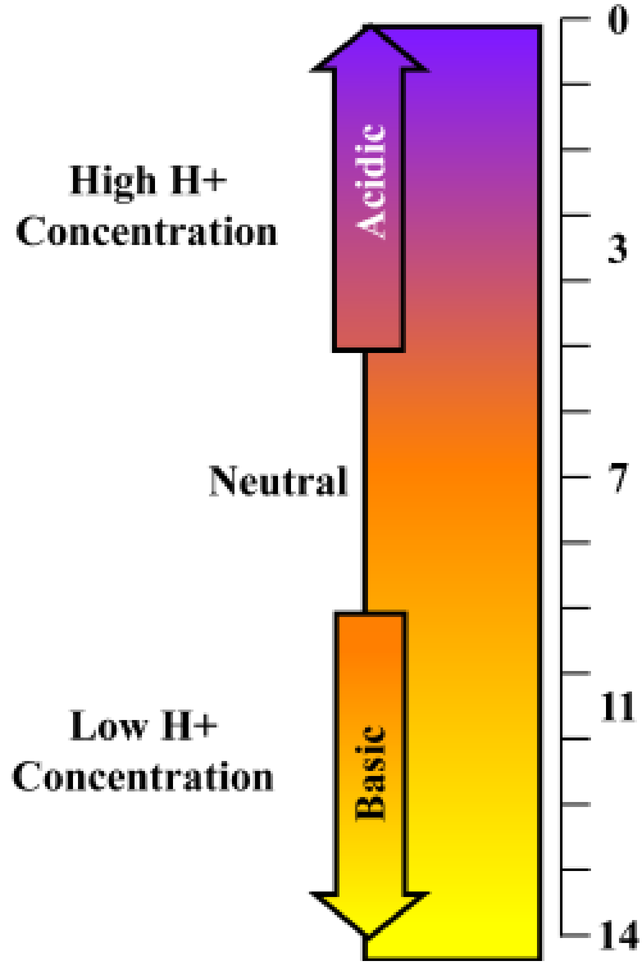
This is called **liming**. Liming also adds a plant food, calcium, which may be deficient in extremely acid (such as some of our local volcanic or our wetland) soils.

Dolomite, or dolomite limestone, has another plant nutrient, magnesium, in addition to the calcium in it. It is usually better for liming when it is available. There is not much that can be done, other than using expensive extra fertilizer, if a soil is too alkaline.

If they are deep enough and carefully farmed, limestone soils may be good for agriculture. If one is careful to continuously add compost (organic matter), the *humic acid* produced can offset the soil's natural alkalinity.

They might, however, need special extra fertilizer along with some trace elements. This is because the surplus calcium (from the calcium carbonate of the limestone) tends to make phosphorous less soluble.

A few very special plants are found only on soils that are either very acid or very alkaline. To protect these we should preserve some of these areas in their natural condition. This will prevent some plants from becoming extinct, and it will protect the biological diversity and beauty of our islands. Wetlands are one example.



The pH scale

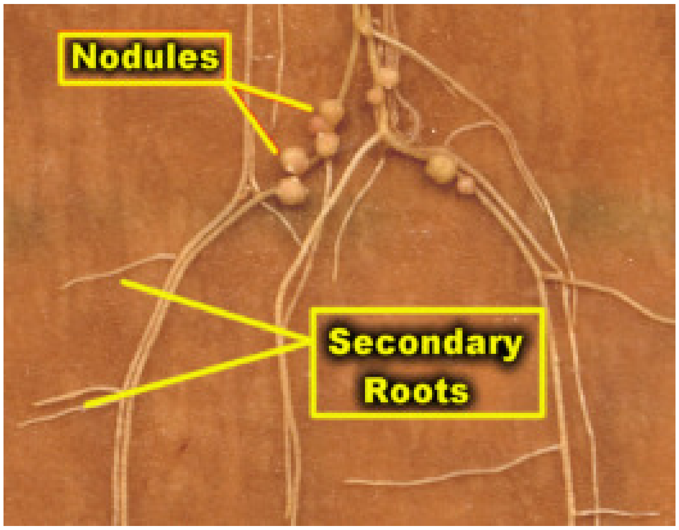
26. 4. 7. Nitrogen

Good soils also have lots of organic matter, both dead and living. The amount of organic matter that stays in well-drained soils varies with the amount of nitrogen in the soil.

More organic material and living things also tend to keep more nitrogen in the soil. Usually, the darker the surface, the more organic matter present, as well as nitrogen and other plant nutrients.

Some living things even **fix** (chemically change or fertilize) nitrogen from air into a soil. This "fixing" makes more nitrogen available, forming rich soils (soils that are best for agriculture).

These include a group of bacteria (called *Rhizobium sp.)* that live in a symbiotic partnership with certain plants, especially those called **legumes** (a family of plants with pods that open up, like the pods of beans).



Nodules on a legume's roots act like fertilizer factories for the plant.

These plant/bacteria partnerships form **nodules** on the plant's roots which act like fertilizer factories for the plant. *Acacia* and *Casuarina* trees also have root nodules. With care, rich soils may tend to improve, but badly damaged soils only improve very slowly.

26. 4. 8. Forest Soils, Nutrient Recycling and Slash/Burn Tropical Farming

Plant foods tend to be held by organic matter and are recycled by living things in the soil. This keeps plant foods from being washed away as soon as they are dissolved out of rock, fixed from the air, added by humans, or washed or blown in from somewhere else.

Since forests usually have lots of twigs and leaves falling to the ground, lots of organic matter and life accumulate in forest soil. This means that forest soils are often very rich. (Note: this is true for tropical soils but is not necessarily so in temperate climates).

A land owner must be careful to keep the soil in good shape (especially high in organic matter) after the forest is cleared for farms or gardens. This is best done by keeping vegetation cover as constant as possible to protect the topsoil.

Tropical soils, however, are often very low in nutrients, but they can support rich vegetation because they have developed over a long time.

Slash and burn farming practices provides nutrients for only a couple of years.

Some tropical forest soils depend completely on plants to hold the plant nutrients that would otherwise be washed out of the soil by their high rainfall climates.

Slash and burn farming practices provides nutrients for only a couple of years. When the plants are cut down or burned, the nutrients from the organic matter in the topsoil are soon washed away. Often, so is a lot of the soil.

The leaves and other organic material are no longer supplied by the trees and so there is often not enough new organic material to replace that which is lost due to runoff and that lost by natural **infiltration** (leaching through a soil's lower layers). Tropical farmers often have to abandon the land and move elsewhere.

Here in the CNMI many farmers don't have the opportunity to *move on*, so here a system of crop/forest rotation within one's agricultural lands is called for.

26. 4. 9. Fire Ecosystems

Often tropical farms, developed on what used to be tropical forests, fail or are abandoned in three to seven years. The trees are then replaced with grasses which burn very easily.

This man-induced **fire ecosystem** (a local condition dependent on having frequent fires) is extremely flammable. These areas accumulate very little soil between the fires. The frequent fires kill any tree seedlings. Eventually all the forests' tree seeds sprout and are then destroyed. Soil nutrients get rapidly depleted.

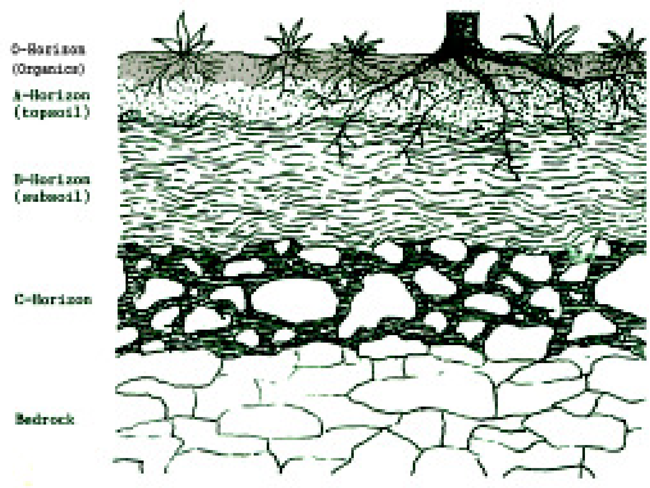
Grasses are adapted to frequent fires. Grasses, however, contribute much less organic matter to the soil than do tropical forest plants. Grasses are drier and more flammable as well.

Because the original trees are gone, there are no more seedlings to replace the cut trees. We have no idea how long, if ever, it will take the forest to return to these places.

26. 5. THE SOIL PROFILE AND SOIL HORIZONS

26. 5. 1. The A, or Topsoil Horizon

Soils are usually found in several layers which together are called the **soil profile**. The layers in a soil profile are called **horizons**.



Soil Horizons

The top horizon is called the **O-horizon** (discussed below) and the **A-Horizon** is directly beneath this. The common name of the A-horizon is topsoil. It is high in organic matter and darker in color, because dead organic matter is usually dark brown or black.

26. 5. 2. The B, or Subsoil Horizon

From the topsoil, many of the minerals are dissolved and carried down to a lower layer, the **B-horizon**. This is sometimes called the zone of accumulation because it receives materials from the A-horizon by a process called **leaching**.

Leaching is a process in which water dissolves minerals and moves them out of a layer of soil. Occasionally, part of the B-horizon can cement together, often caused by heavy machinery, into a **hard pan** (a hard layer) that may interfere with drainage and farming.

Subsoil is another name for the B-horizon.

26. 5. 3. The C, or Parent Material Horizon

Subsoil is transitional to the layer below it, the **C-horizon**. The soil profile usually rests on rock, which is called **bedrock** or **parent material** (really the stuff the *bedrock* is made of).

The C-horizon contains the broken parent material (limestone or volcanic rock) that forms the upper layers. It is an area where, if we dig down, we move from soil to parent rock.

26. 5. 4. The "O", or Surface Organic Material Horizon

In the forest, on flat land, and in poorly drained low spots of the CNMI, there may be a very thin layer of almost pure organic material on top of the soil. Locally the greatest abundance of O-horizon formation is in our marshes and swamplands.

This is the **O-horizon;** it is a very fertile layer that, unfortunately, is rarely seen on cleared farm land. The O-horizon is usually black or dark brown and is often found as either a muck or peat. Muck feels very greasy when wet. Peat has leaves and stems of plant material that have not decomposed.

26. 6. SOILS IN OUR MARIANAS

26. 6. 1. Types of Island Soils

There are three kinds of islands in the Pacific: continental, volcanic and coral.

"Continental islands" refer to very large island masses, including the main islands in the Japan, Philippine, Indonesian, and Papua/New Guinea archipelagos. These massive islands all used to be attached to continents.

Only coral islands and volcanic islands occur here in the CNMI.

Soil comes from a parent material, such as volcanic rock or coral rock, which is related to whether the island is continental, volcanic, or coral. Here in the Marianas therefore, as mentioned above, the two main parent materials are volcanic rock and limestone.

Volcanic Ash

26. 6. 2. Volcanic Soil Features

Volcanic islands form from melted rock, lava, or sand-like **ash** blown out of volcanoes. Ash is interesting because some of the minerals in it dissolve easily.

With added water in a warm climate, ash may quickly develop into a good soil after being blown out of the volcano.

The addition of other things, especially living things and their decayed and decaying parts, can make it even better for growing plants. Farmers may soon return to their land after certain kinds of ash have covered it.

Soils formed from volcanic rock are usually deeply weathered in tropical areas. The B-horizon in volcanic soils is high in iron and aluminum.

The color of this soil is usually reddish or yellowish. This is because the iron has reacted with oxygen to form **iron oxides** like rust, which have a red or yellow color.

Soils which are high in iron oxides are usually reddish or yellowish in color.

Volcanic soils may also be gray or purple, with streaks of blue or green especially if poorly drained. Volcanic soils often have poor water drainage. Bottomland volcanic-derived soils, with deep clays, are particularly slow draining.

They may be shallow or deep, and locally, are usually acidic, but not extremely acidic. This is due to the fact that the CNMI's soils still have basic minerals to weather. Guam island's southern volcanic soils, on the other hand, are older, more weathered, and more acidic than those here in the CNMI.

26. 6. 3. Limestone Soil Features

Because limestone gets weathered as its calcium carbonate rock make-up dissolves, not much material is left behind to make a soil. In fact *pure* calcium carbonate weathers completely to carbon dioxide gas and calcium-rich *hard* water.

This fact has spawned a mystery amongst soil scientists worldwide who work with soils originally formed from a limestone parent material. Where did the soil itself come from?

If pure limestone rock turns into gas and mineral-rich water, what gets left behind (or added) to form the surface's soil? It can't be from pure limestone, since this gets weathered completely into hard water (which enters the groundwater) and carbon dioxide gas (which escapes into the air).

One hypothesis goes like this: what is left, after weathering, to make a limestone soil, are "the impurities" in the limestone itself. For example, these impurities may include clay and a few minerals perhaps "fixed" over time onto a reef from the nearshore ocean water by a reef's own sea life. The reef later gets raised through faulting, is weathered, and the remaining "impurities" become the basis for the soil.

Another common hypothesis is that mineral-rich volcanic ash from the same or from a more remote island serves as the foundation of an island's limestone soils.

Still a third hypothesis scientists are studying is the concept that **loess** forms the basis for limestone soils. Loess is a general name for airborne dust-like rock particles. These particles often come to a region from sources hundreds to thousands of miles away from the place they eventually land upon.

Loess particles are scraped off (sandblasted-off is more descriptive) of bare rock surfaces by scouring winds. Once airborne they don't fall until they are relocated miles elsewhere. Desert rock surfaces often erode to loess during sand storms.

Ironically, many scientists feel that our islands' limestone soils have, as their foundation, rock fragments derived from deserts thousands or tens of thousands of miles away.

Because of its dissolution, limestone is often **porous**, meaning full of holes or channels.

Therefore, a limestone soil is usually a very thin soil with very good drainage because of good soil structure and a porous parent material below it. Water usually does not stand for very long in puddles on a limestone soil after a rain.

Thin soils are hard to farm and dry out more easily than deeper soils. The soil formed from limestone usually has a red color and is alkaline, but, as mentioned, it is not often extremely alkaline in the CNMI.

26. 6. 4. Soils and Biodiverisity

The type of soil determines the types of plants that can live in an area, and the types of plants determine what animals will be found there.

Both the volcanic and the limestone soils support communities of plants and animals that will only be found on that type of soil. In the interests of preserving island biodiversity, all sorts of soils should be included in our parks and natural reserves.

Erosion is one of the worst problems of tropical Pacific Islands.

26. 7. SOIL EROSION AND LATERIZATION

26. 7. 1. The Wind and the Rain

Erosion, the removal of soil by rain and wind, is one of the worst problems of tropical Pacific islands. Erosion can occur even on flat land, but it is much, much worse on sloping land. The greater the degree of slope, the greater the danger of serious erosion.

26. 7. 2. Causes of Erosion

Often, the effects of erosion make it hard to prevent further erosion. It is cheaper and easier to prevent it in the first place.

In nature, soils are almost always covered by forest, grassland, or other vegetation. When the soil is uncovered, erosion becomes a problem. The protective soil layer is removed by fires, by logging, and by clearing for agriculture, construction, and similar activities.

Soil conservationists apply the following formula to estimate the loss of soil from an area as it is subject to different land use practices and different percentages of plant cover. It is a useful planning tool.

Revised Universal Soil Loss Equation

A = R x K x LS x C x P

Where:

A = Average Annual Soil Loss in Tons per Acre Per Year
R = Rainfall-Runoff Erosivity
K = Erodability of the Soil
L = Slope Length
S = Slope Steepness
C = Cover-Management
P = Support Practice

26. 7. 3. Our Valuable Topmost Soil

The top 15.2 centimeters (6 inches) of a good deep soil is the main part of the **root zone**, where the roots of most crops are. This main part of the root zone is also called the **plow zone**. To have the best crops, we would like all of this to be topsoil. The full extent of the root zone goes down to the depth of a limiting layer, like an area's bedrock.

Because the top six inches weighs two million pounds per acre, it would take a lot of trucks and loaders quite a while to put that much soil back onto a single acre. This is why people buy farms for their soil instead of buying the soil for their farms.

The roots of certain vegetable crops can be found in deeper soils, ranging from one to about three feet deep. Tree species (fruit trees, agroforests, etc.) have an even deeper root zone.

26. 7. 4. Our Shallow Soils

CNMI soils, however, are often much more shallow than six inches and often have massive rock directly under them. We do not want to expose any of this precious soil on our land to loss.

Since most of the plant food is found near the top of the soil, farmers especially cannot afford to lose any of the surface soil. The more that is lost from the top of the soil, the harder it is to grow things in that spot, even though in other spots a soil may be a couple of meters deep.

26. 7. 5. Exposed Soils

Whether a soil is laid bare because of human activity or because of fire, it is then easily subject to damage. The bare soil becomes exposed to wind, rain, running water from higher up, and the baking sun.

Erosion by water is an even more serious problem than wind erosion.

The tropical sun's infrared heat on bare, exposed soil causes its organic matter to dry out and quickly evaporate away. This occurs much like when a researcher intentionally removes the organic matter's percentage by baking a soil sample in a laboratory's drying oven.

When the soil is dry, wind can blow it away into the sea. Wind erosion is a problem for many soils. It can be especially bad for soils with valuable high organic content. Local soil scientists have found that wind is not nearly so severe a local erosion problem as is water and water-caused soil runoff. Windbreak plantings of high and dense growing trees are recommended, however, to cut down moisture loss from transpiration.

26. 7. 6. Runoff Processes

As mentioned, erosion by water is a more serious problem for our islands. Most erosion in the CNMI is caused by water. Beating rain knocks small pieces of soil and **runoff** (running water from above) carries them away as muddy water.

Running water, especially on steep slopes, builds up speed to tear pieces of soil loose. Then these pieces hit other pieces of soil, knocking more soil particles loose. If sloping land is left bare of vegetation, this can cause enough erosion to ruin the soil after just a few storms.

Saprolite is composed almost entirely of well-weathered volcanic ash or some other soil-forming loess material.

26. 7. 7. Effects of Sedimentation

Often, erosion is not noticed by anyone. This is because only a small layer is washed or blown away each year. Sometimes *all* the topsoil is lost to erosion, leaving either bare rock or **badlands**.

Local badlands are areas where an infertile, loose underlying material called **saprolite**, is exposed. Saprolite is composed almost entirely of well-weathered volcanic ash or some other soil-forming *loess* material.

Local badlands have little to no overlying vegetation other than swordgrass. Hardly any organic matter is retained within them. Erosion here is severe and occurs continuously each time it rains, displacing much soil and subsoil material to downstream areas.

The displaced soil material (now called **sediments**) often ends up smothering streams, lagoons, and reefs. This is called **sedimentation** (re-depositing of sediments).

When erosion occurs, the traveling soil may make the careless landowner very unpopular by ending up in someone else's front yard. Worse still, it may end up on reefs or in the lagoon and do very serious damage (see Ch. 15, Coral Reef Problems).

Most high island farmers are already farming in or near the subsoil.

26. 7. 8. Leaching

In very wet places like the Marianas, water trickling down through the soil can wash most of the food elements (nutrients) down to the water table.

From there, they eventually move into streams or springs, again leading to our reefs and lagoons where these nutrients can cause significant habitat damage. Growing plants and organic matter in the soil can prevent this by taking up almost all the nutrients.

26. 7. 9. Forest Clearings

As suggested earlier, in wet tropical forests, the clearing of the forest may spell disaster for the soil because of nutrient loss.

After the forest is removed, the sun dries out the soil and reduces the amount of life at or near the surface. The result is that there is less living stuff going into the soil and the organic matter that decomposes is not replaced.

26. 7. 10. Laterization

Subsoil has very little organic matter in it. Unfortunately, many, perhaps most, **high island** farmers are already farming in or near the subsoil. This is particularly true in Belau, Pohnpei, Kusaie, and other high Micronesian volcanic islands.

If clayey (heavy) soils high in iron are exposed to the sun for very long, the surface may turn to a rock-like substance. This is especially true of soils that have lost their A-horizon. The exposed soil surface becomes almost as hard as concrete. The name for this process is **laterization**.

The word *laterization* is also used in another way, however, to describe the development of soils under high rainfall conditions.

This process can form soils that are almost nothing but oxides (like rust and corrosion) of iron and aluminum. Weatherable minerals tend to be oxidized and washed away, and red-brown soils tend to form.

Although this process is important in the Marianas, it is not the whole story. Our volcanic soils differ from tropical soils formed from volcanic rock in places such as the Federated States of Micronesia and Hawaii. Our local volcanic soil's parent material is different.

Our predominant volcanic rock tends to be andesite.

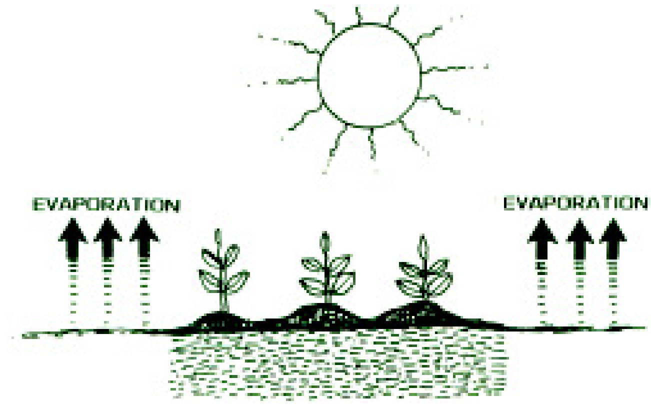
Instead of **basalt**, our predominant volcanic rock tends to be **andesite**. You may recall that andesite has a much higher percentage of the mineral "silica" (**SiO_2**) in it than basalt. In our soils, because silica doesn't oxidize, the process of *laterization* is often incomplete.

26. 8. SOIL CONSERVATION

26. 8. 1. Mulching

The solution to erosion and laterization is to prevent them by keeping the soil covered as much as possible with growing plants or with **mulch** (some sort of surface covering), such as dark plastic or dead plants.

The plastic must not let much light through, or **weeds** (plants harmfully out of place) will grow up through it. Black plastic sheets are popular; however, black plastic that is silver on the top side is even better because insects like aphids avoid it as they do the surface of a lake.



Mulching saves soil moisture by slowing down evaporation.

26. 8. 2. Using Natural Mulch

Putting lots of cut straw or other plant waste over bare soil is a more natural mulch. This also controls small-seeded weeds and can improve the soil.

Because organic matter decays so fast, it is always good to apply natural mulching materials, such as leaves, grass cuttings, and similar organic matter, to a soil's surface as often as possible.

Even washed up seaweed can be used for mulch if it is left exposed to the rain for awhile. This is necessary to wash out the sea salts before applying it to a soil.

26. 8. 3. Earthworms and Other Beneficial Soil Organisms; Numbers and Actions

When the field is plowed or turned later, the surface's organic matter will be mixed in. Even prior to this, insects and worms will mix a lot of it into the ground anyway.

One reason it is best to use as little pesticide as possible is because these small creatures, especially earthworms, are so useful in the soil. This is not a small matter: there may be 50,000 earthworms in every acre and far more soil insects and mites.

26. 8. 4. Compost

Composting is a process in which plant material—with perhaps some table wastes and farm animal wastes—is kept moist, but not too wet, in a pile or a pit until it turns into humus. It is used for soil improvement because it adds organic material and some major nutrients and micro-nutrients.


Composting is used for soil improvement because it adds organic material and some major nutrients and micro-nutrients.

Compost piles and pits tend to become very warm because of the rapid decay (caused by aerobic bacteria) which takes place. They must be turned often, perhaps about once a week, to let air into them.

Otherwise they can become anaerobic (without air), slowing down the rate of decay. Compost piles should be kept damp and not allowed to dry out.

If the rainfall is too high, or too much water is added, the plant food (nutrients) may be washed away and the compost will not be as good. Therefore, it may be necessary to put a roof, perhaps made of thatch, over the compost pit. Be sure, however, to keep the compost pile moist.

Minimum tillage can prevent erosion and laterization.

Adding small amounts of ground rock phosphate or other phosphate fertilizer, such as *super-phosphate*, may also help the quality of the final product. Bacteria also need nitrogen to live and some nitrogen fertilizer can also be beneficial.

The plant material being broken down contains a third necessary ingredient, carbon. Composters should try to have a good ratio of nitrogen to carbon in their compost pile for the quickest plant decay possible.

Wood ashes may also help. It is important, however, that burned metallic and chemical contaminants (including wood preservatives) never be allowed to be included with the wood ashes.

Finished compost resembles a dark brown or black soil and ranges between 2% and 10% nitrogen, depending upon its constituents. Read more about composting in our Farming chapter (chpt. 30) and in our Landscaping chapter (chpt. 42).

26. 8. 5. Growing Plants with No "Soil"

Several Pacific *atoll islands* have no soil whatsoever. These islands' residents grow all their crops on specially cared-for compost-like beds. Such beds have taken hundreds of years of nourishment to build. The great-great-great-great grandparents likely started them.

Using traditional knowledge and methods, people living on these atolls work hard to maintain their life, their culture, and most importantly, their future's life-giving compost beds.

As one might imagine, given the choice of death or life, they really appreciate the value of having something, even though it is not soil, to grow their food in.

Several of our local farmers use an introduced, locally-grown tall legume called sunn hemp.

26. 8. 6. Using Care in Applying Fertilizer

The proper addition of fertilizers helps feed crops. It helps maintain the organic matter in a soil when crops are harvested and substitutes for harvested plant nutrients.

Applying too much chemical fertilizer can be expensive and wasteful. It tends to wash away and end up as **pollution** (meaning something harmfully out of place) in the ground water and eventually, our lagoons and reefs.

26. 8. 7. Minimum Tillage

Disturbing a soil as little as possible is another way to prevent erosion and laterization. This approach is called **minimum tillage**.

Small scale and even relatively stationary traditional farming does not uncover entire fields of soil all at once like modern farming calls for. After any tall extra vegetation is cut down, the soil is only opened enough for a single hole for each plant.

Suppose a field were covered with dead plants like grass or straw. The best way to use it for a crop would be to make a little hole for each crop plant. This way the rest of the soil would be covered and undisturbed.

26. 8. 8. Using Sunn Hemp as a Cover Crop and "Green Manure"

One local **cover crop** method of planting is to plant and grow the desired crop plants only after first growing a noncrop *cover plant*.

After the noncrop plant dies back, its leaves can cover the ground thus preserving the soil. It is important that such cover crops do not re-seed or grow back on their own from dormant roots.

Several of our local farmers use an introduced, locally-grown tall legume called **sunn hemp** (*Crotalaria juncea*). Like other legumes, it hosts bacteria within its roots that fix nitrogen into the soil while it is growing.

Contour planting helps reduce erosion on sloping land.

Sunn hemp needs human help to reseed. It dies when it is cut down and left at the end of the season. The resulting dead sunn hemp covers the soil as a thick accumulated mulch. The need for human help to re-seed is important since many introduced plants have gone wild and have caused problems as time went by.

Sunn hemp is sometimes used as a **green manure**. Before it flowers, it is plowed under, providing nitrogen and organic matter to the soil. After the sunn hemp dies, it is possible then to clear small holes, or cut narrow rows, and then plant one's crop plant or seeds between the accumulated mulch.

In this way there is almost no disturbance for a crop or two after the sunn hemp "treatment".

Our shrub Leucaena (Tangantangan) has been successfully used for erosion reduction.

Local farm treatment with sunn hemp is experimental but it may well prove to be very useful for growing crops in the wet season, when we usually cannot or should not plow or expose the soil (recall the *puddling* problem?).

Produce buyers desire a year-round supply of food. Our farmers have a hard time marketing their vegetables unless they can supply a product all year round.

26. 8. 9. Contour Plowing and Planting

To reduce erosion on land that slopes noticeably, rows should be planted across the slope, that is, *around* hills, never *up and down* them. This making of rows—across the slope—is called **contour planting**.

Farming on the contour can reduce erosion by half on fields with less than a seven percent slope. If the slope is too steep, not planting at all is best.

However, we can carefully farm on slopes that are steeper than usual, by contour planting rows of **perennial** (meaning long-lived) plants that grow in thick permanent rows with rows of crop plants grown between them.

These can be perennial grasses or hedges (these are called **hedgerows**). Crops are planted in strips between these rows (called **stripcropping**).

These perennial plants serve to hold the soil. They can be top clipped for vegetative-mulch purposes but their roots are allowed to remain intact.

Our shrub/small tree *Leucaena* (Tangantangan), certain grasses such as Vetiver grass (*Vetiveria zizanioides*), and even *Asparagus* (on very high islands elsewhere in Micronesia) have been successfully used for this soil-holding function.

Using fire to clear the land can damage soil.

26. 8. 10. Contour Planting

Certain grasses have been reported to catch soil so well in some parts of Asia that they form **terraces** (flat shelves on the hillsides). The *Leucaena* grows well in the Marianas Islands and can be used as shade, or can be cut short.

Plants growing in partial shade need much less fertilizer than they do in the sun. People use *Leucaena* trimmings for cattle feed, for fire wood, and for mulch. Since *Leucaena* is a legume, it also supplies nitrogen to the soil. Several other species are also used locally as hedgerows.

Asparagus has been successfully used at high altitudes in some tropical areas, but it would need testing at our lower altitudes here in the CNMI. *Asparagus* is usually considered a colder and wetter weather plant than our local climate allows.

Vetiver grass has been tried and has proven very successful locally. Whatever perennial plant is chosen to hold the soil, plantings can last for generations if well cared for.

26. 8. 11. Contour Planting with Tree Crops

Tree crops may be used to replace forests, but they may not be as good for the soil as were the native forests, especially on slopes.

On steep slopes, plant trees on the contour with some faster-growing plant such as grass or sunn hemp in alternate rows to hold the soil while the young crop trees grow big enough.

On less steep land, some sort of mulch may still be essential to protect the soil while trees or other perennials are starting.

26. 8. 12. Using Fire

Fire makes a good sterile seed bed. However, using fire to clear the land or burn weeds can also damage the soil. At first, nutrients in the plants are quickly made available in the ashes, but these ashes are also easily blown away by wind and washed away by rain.

This is like burning the pig pen to roast the pig. It might work at first, but then we could not get on well afterward.

Burning also removes leaves and other organic matter that could help keep the soil organic matter high. The result is that the soil becomes lower in organic material and less able to hold water and nutrients in place.

Such soil is noticeable for drying out quickly. As mentioned earlier, resulting erosion is another severe problem with fire use.

26. 8. 13. Our Salt Problem

Too much salt keeps plants from taking in enough water. Too much fertilizer or too much sea salt affects the water absorption by plants. Some low-lying island soils are badly affected by sea salt during storms, or by the sea coming up into groundwater in the root zone.

A related problem is seawater coming into the ground water from wells. The most common salt, whether sea or fertilizer, replaces the other salts in the soil's organic matter and clay.

Many wells on Saipan are contaminated with sea water. When this water is used for irrigation, sea salt accumulates in place of fertilizer salts. The sea salt (sodium chloride) may even get too concentrated for the plants to grow at all. The accumulation of salts is called **salination**.

High salt content, especially sea salt on heavy soils, can reduce or ruin crop yields for a very long time. Salination may be reduced by adding lots of water and **gypsum** (which is very expensive).

Overused wells are likely to be saltier than moderately used ones, especially if the neighboring wells are only moderately used. We must conserve water to be sure of having good water when we need it.

26. 9. FERTILIZING SOILS

26. 9. 1. The Reason to Add Fertilizer

Plants take nutrients out of the soil. When we harvest crops we take some of the soil's plant food away with our harvest. The more of the plant that we leave behind to decompose and return the nutrients to the soil, the better.

Big harvests mean a lot of plant nutrients are carried away. The land may become useless unless we let it rest or add some nutrients to replenish the soil.

Soil-improving crops, like these soybeans, add nitrogen to the soil.

26. 9. 2. Soil Resting and Crop Rotation

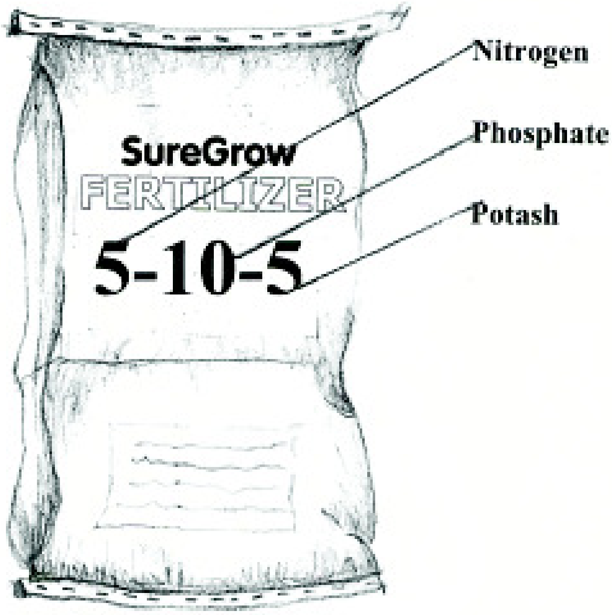
Resting the soil helps it to catch up because it slowly fixes nitrogen and it slowly gets other nutrients from the weathering of minerals.

We can use the soil a little longer by using **crop rotation** (using a different crop each time we plant). This is because different crops use different nutrients.

Soil-improving crops, such as beans and other legumes, which add nitrogen to soil, should follow soil-depleting crops like most other vegetables.

In the tropics especially, something must be growing and covering the soil when it is resting, or it and the newly fixed nitrogen and the remaining nutrients will be washed away.

Crop rotation also breaks pest cycles. For example, nematodes on tomato roots can live in soil for only a couple of years.



N, P & K are listed as the first three numbers on many fertilizer bags.

26. 9. 3. Fertilizing Materials

There are several ways to fertilize a crop. One is to add plant material from somewhere else to the soil. Another is to add animal wastes, or similar stuff—such as piggery manure or even sewage sludge—to the soil. The most popular modern fertilizer however, is chemical fertilizer.

26. 9. 4. Fertilizer Formulas

NPK stands for nitrogen (N), phosphate (a form of phosphorus) (P), and potassium (K). They are listed as the first three numbers on many fertilizer bags. So, 2, 3, 7 stands for 2% nitrogen, 3% phosphorous, and 7% potassium.

26. 9. 5. Applying Fertilizers

One hundred pounds of a weak fertilizer like 3, 3, 3 costs a lot more to ship to our island than 25 pounds of 12, 12, 12, a strong fertilizer, but we still get the same amount of plant food in each.

If we need 3 pounds of nitrogen, 3 pounds of phosphorous, and 3 pounds of potassium per acre to feed our crop, then it will be cheaper to buy and spread 25 pounds of the strong fertilizer than 100 pounds of the weak one. We will still give our plants the correct amount of nutrients either way.

We can use strong fertilizers on our soil with good results unless we use too much. If we put on too much, the extra fertilizer eventually ends up in our rivers, the lagoon and reefs, our well water, or in some combination of these.

If our soil is less than six inches deep, we should put on only a reasonable proportion of what we would put onto a deeper soil.

For instance, if our soil is only three inches deep, we can put on half as much fertilizer now and (assuming there is rain and plant growth), then put on the other half after about a month (perhaps just after the fruit sets and before it starts to ripen).

Too much fertilizer can cause fertilizer burn.

26. 9. 6. Too Much Fertilizer Can be Very Harmful

Overuse of nitrogen fertilizers can cause many problems. A disease called **methemoglobinemia** has been traced to excessive amounts of nitrogen in untreated or inadequately treated groundwater that is used for drinking water.

The excess nitrogen of fertilizers can leach down into the groundwater. Wells bring the nitrogen contaminants back to the surface. Infant children are most vulnerable to these excess nitrogen amounts.

Under the US Clean Water Act, states, commonwealths, and territories must all apply drinking water standards that require nitrogen levels to be below safe thresholds.

CNMI drinking water standards apply to all public water facilities. The regular monitoring of drinking water can help to guard against excess nutrient levels. Groundwater nutrient monitoring needs to be encouraged as well.

Too much fertilizer can also cause **fertilizer burn** (an excess salt problem) and kill the crops. Many farmers need training in the proper application rates and methods for both fertilizers and pesticides. Several Commonwealth and Federal programs offer such training.

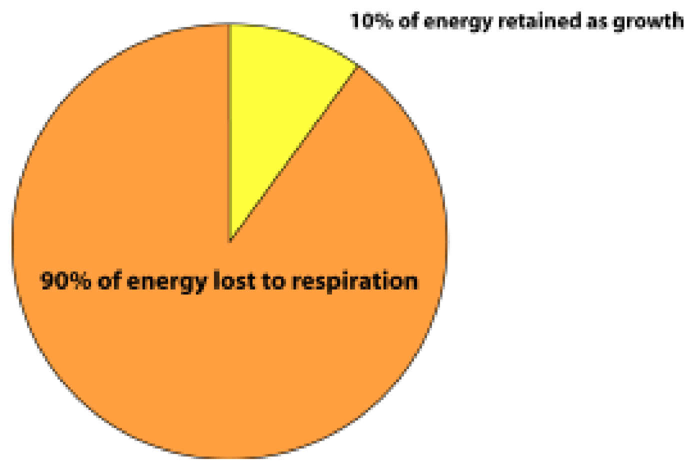
26. 9. 7. Metric Amounts
Incidentally, it is handy to know that the conversion from pounds per acre to kilograms per hectare is easy.

It just happens that the six inch plow zone for an acre weighs 2,000,000 pounds and the same plow zone for a hectare weighs 2,000,000 kilograms.

Thus, if we are supposed to put 200 pounds of a fertilizer on each acre, we can put 200 kilograms on each hectare instead.
1 hectare = 2.47 acres
1 kilogram = 2.205 pounds

26. 10. SOIL ECOLOGY

26. 10. 1. Introduction
There are a number of ways of looking at the ecology of soils. Let us move through the soil environment with a discussion of energy. We will learn how **toxic** (poisonous) pollution increases as the stored energy decreases at each step of a food chain.



Even though organisms are somewhat energy efficient, they still lose 90 percent of their energy through respiration.

26. 10. 2. Energy Transfers
Energy is what is needed to do work. However, the **first law of thermodynamics** tells us that *energy is neither created nor destroyed.* People and other organisms do not use up energy, they participate in the movement of energy from where there is lots of energy to where there is less energy.

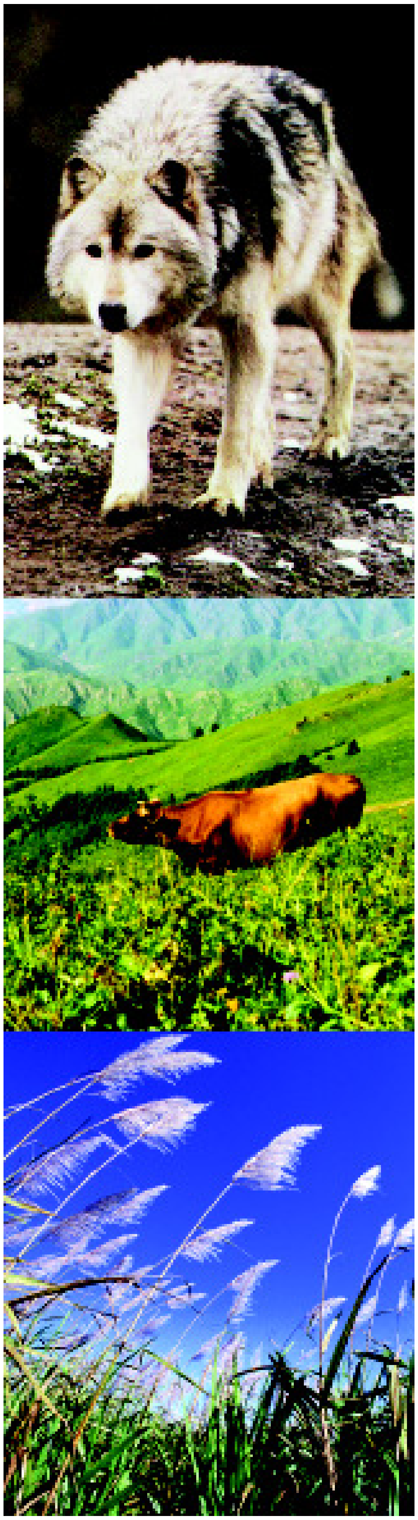
When we refer to *using* the energy from something, we really mean using the movement or transferring of energy. Often this starts as stored energy such as the energy stored in food.

No process of using energy is perfect. Just like machines which, through friction, always lose some of their fuel's energy as heat, living things lose a lot of energy as they use their food.

Organisms are somewhat **energy efficient**, meaning that they waste less energy than do most human-made machines. Even so, consumer organisms will retain as growth, only ten percent of the energy contained in their food.

We may think of this 1/10th energy amount as still being stored in the environment. Ninety (90) percent is lost as respiration.

26. 10. 3. Energy, Fuels, and Photosynthesis
Energy is in wood waiting to be burned and in sugar or fat waiting to be used (metabolized) by an animal. It exists as light or as concentrations of heat in places that are hotter than others, like above a fire.



From bottom to top: producers, primary consumers, secondary consumers.

Almost all organisms depend on energy coming from the sun in the form of light. Living things store energy as stored foods. This gives them their weight.

Recall that plants have a green **pigment** called **chlorophyll** that allows them to capture and store solar energy. This energy comes from the sun as light. The capturing and storage process is called **photosynthesis**.

Some of the light that is not captured is reflected away towards space. Some of it becomes heat energy and makes the plants and other things become warmer.

The atmosphere loses heat to the coldness of space all the time. Otherwise, the world would become a very hot place. So, we have energy arriving from the sun, a little being captured or used for transpiration, and the rest warming the air which eventually loses its heat to the cold hugeness of space.

26. 10. 4. Using Stored Energy

For the activities of organisms, the stored energy must be removed from storage, and used for growth and movement. At each step, more of the energy becomes respired heat and is lost. Remember however, the sun is constantly sending more energy for the plants to capture.

Using the stored energy from sunlight, plants use water, carbon dioxide, fixed nitrogen, phosphorous, potassium, sulfur, and many other mineral elements to grow.

26. 10. 5. Producers and Herbivores

Because plants capture the light energy to make almost all of the world's organic material, they are also called **producers**.

Producers can be eaten and used as a source of stored energy for other organisms, the **primary consumers** (the first ones who eat material from the producers). Primary consumers that eat fresh plant material are also called **herbivores** (plant eaters).

26. 10. 6. Food Chains and Energy Loss

The only way we can get food energy from the sun is to eat a plant, to eat something that ate a plant, or to eat something else that ate something that ate a plant.

Organisms that eat primary consumers are called **secondary** (for second) **consumers** (users) and organisms that eat them are called **tertiary** (for third) **consumers** and so on, to make a **food chain**.

The energy stored by photosynthesis flows along this chain. About 90% is lost at every step, until very little is left. As a step in the food chain loses 90% of the energy going into it, it also loses 90% of its weight.

Predators (also called **carnivores**) eat live organisms; other animals called **scavengers** eat dead organisms. Along with the scavengers are the **saprophytes** (plant-like decay organisms such as bacteria and fungi) which get their energy by dissolving dead things.

26. 10. 7. Soil Pathogens

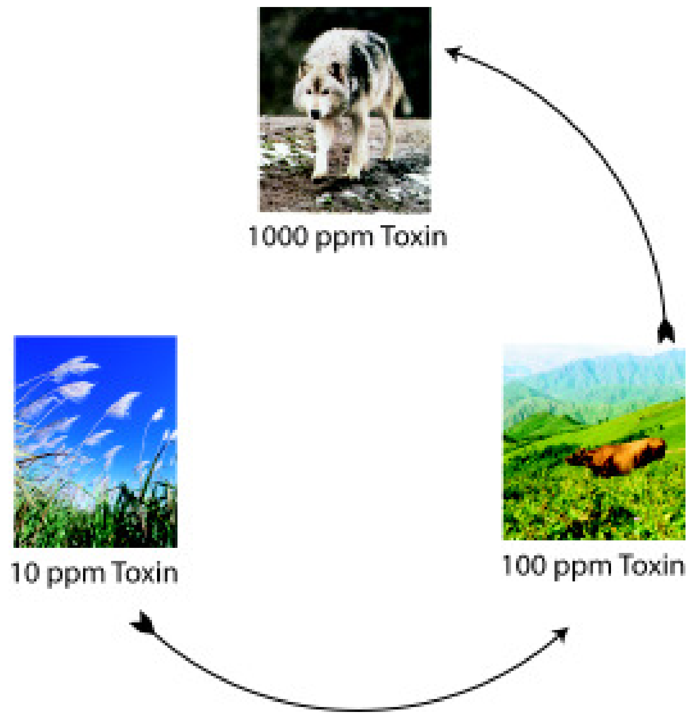
Most disease organisms, **pathogens**, are either animals or plant-like organisms that behave a little like predators because they usually live by eating their victims. However, a few are like saprophytes, some of which put out terrible toxins.

One of these that is found in soils is the tetanus organism, *Botulinum tetani.* Tetanus can also live in deep closed puncture wounds on humans, and fatally poison them. It does this even though it is only feeding on the dead tissue in the wound.

Everyone, especially children, plumbers, and gardeners, should be vaccinated with boosters every ten years against this disease. It is not unusual for those unvaccinated to die unpleasantly from tetanus after even a simple thorn wound.

26. 10. 8. Biomagnification

While the stored energy in the food chain decreases, many kinds of pollution increase. The pollution is *concentrated* (is collected together, the opposite of diluted) as it moves through the food chain. This phenomenon is called **biological magnification.**



While the stored energy in the food chain decreases, many kinds of pollution increase.

We will use weight loss to indicate energy loss in our example. This is because the weight of living material relates to how much energy is stored in it.

Suppose someone puts a little pollution here, and a little there, into a field where plants can absorb it. There may not be much at any one place, but this may be the first step in a biological magnification disaster.

On basic (alkaline) limestone soils, for instance, it is possible for heavy metal pollutants, such as lead from our leaded gasolines, to be taken up into plants along with their nutrients.

A kilogram of plant may only have a little lead in it, but earthworms come along and pull the leaves that have fallen off the plant down into their tunnels. This activity is normally a wonderful thing for the soil, because it mixes organic matter into the soil.

However, in this case, the earthworms eat and digest the leaves with the lead in them. The work of collecting and eating leaves and other life activities uses up about 10 kilograms of leaves for every kilogram of new earthworm.

Unfortunately, the worms cannot get rid of the lead and keep almost all of it they eat. So now 1 kilogram of earthworms has ten times as much lead in them than did 1 kilogram of plant.

Birds that eat worms also have to eat 10 kilograms of worm to make 1 kilogram of bird. So we have ten times ten, or one hundred times more lead in every kilogram of bird than we had in one kilogram of plant and the plants may have had more lead in them than did the soil. Birds and earthworms are both very important parts of the environment and we do not want them all to die.

Even worse, if a human, or another predator, such as a hawk, were at the top (the end of the chain in our example) of the food chain and lived mainly on these birds (they could be chickens) for a long time, they would end up with ten times as much lead again. This would be one thousand times as much lead per kilogram of their flesh as was in the plant tissue.

This could make the hawk or human very sick and unable to survive or care for their young. Top predators have historically suffered population declines due to poisoning resulting from such food chains. We humans are often the *top* predators in every ecosystem we are part of.

If people are careless and pollute, the food chain may magnify pollution ten thousand or a hundred thousand times before it gets to the top of the chain. Even a *little* pollution can wreck the soil, or the local environment, or both. Give a hoot, don't pollute.

26. 10. 9. An Ant's Eye Look at the Animal Life within Soil

If we were very tiny, like an ant, we could crawl into a hole in a good soil, perhaps in a forest. If something did not eat us first, we would see large numbers of many kinds of strange things crawling and growing there.


Saprophytes, such as these Pholiota sp., break down decaying organisms.

The larger things and many of the smaller ones would need air and all would need a source of water. Worms and millipedes would seem huge to us, almost like *Godzilla* in a Japanese horror movie. However, they would be busy pulling dead plant stuff into the soil.

Mites would now seem as big as cats, and we would see other insects of many sizes eating dead roots and other dead things. There would be scorpion-like predators, ferocious centipedes, and other (carnivorous) mites and small insects eating both the live and the dead of other mites and insects. It's a tough world down there.

Bacteria, the most abundant soil life, might still be too small for us to see clearly. Fungi would be seen as something like strings everywhere.

These are mostly saprophytes (feeding on dead matter) and would be busy causing the decay of dead things and the wastes of other organisms. (Above ground dwelling mushrooms are the fruiting bodies of these below ground saprophytic fungi strands).

All these things and many more are moving about in every small bit of good soil when it is protected from the sun by the shade of plants. The food chain of many of these organisms may be much longer than the example above.

26. 11. HELP PRESERVE OUR PRIME FARM LANDS

Unfortunately, we humans too often tend to use our best agricultural lands (**prime farm land**) for buildings, for airports, and for roads. It is very important for rural and urban communities to join together to carefully plan the use of our island's scarce land.

This is especially true in the case of our flat, tillable lands, in order to minimize the permanent loss of our prime farm lands. Less croplands, less crops. As our islands' populations increase, scarcity can easily result.

We need to end our common water and soil pollution problems. These include, among others, our unregulated dumps and our unsuccessful septic leach fields.

This is not a matter to be overlooked to avoid a little awkwardness.

Islands such as ours, with growing populations, may easily become bleak and impoverished by *having to* import food, rather than retaining the option—present throughout our long ancestry—of being self-supporting in our food needs.

Indeed, we have always been able to grow crops in excess of local demand—even when there were tens of thousands of Japanese and later, American military troops living amongst us.

Today however, even with our local control over our own economy and land use, we are continuously developing, paving, burning, degrading, and polluting our best farm lands. The buildings and roads which we continue to build will soon make a *crazy-quilt*, covering most of our prime farm land.

Our best agricultural lands, our prime farmlands, are far too often being permanently converted to non-agricultural uses. M*aintaining future options,* whenever possible, is a principal dictum of good decision-making in resource management.

Let us instead try to pass onto our children the rich farmlands we inherited. Let us instead restrict our urban land uses away from the places where our best soils occur, our richest soils, our most valuable soils. Let us instead plan; let us ***plan to protect our prime farm land***!