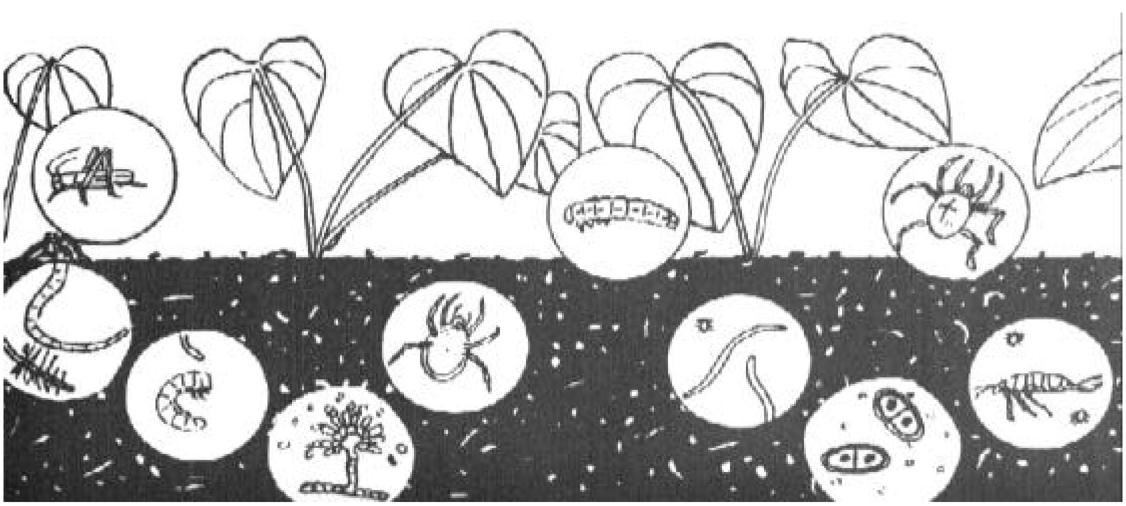
Chapter Three
The Living Soil

This chapter was adapted from: FAO Inter-Country Programme for the Development and Application of Integrated Pest Management in Vegetable Growing in South and South-East Asia. 2000. *Cabbage Integrated Pest Management: An Ecological Guide.* Vientiane, Lao PDR. However, any errors in this chapter are our responsibility.

3.1 What is soil?

3.1.1 Soil includes living things

When you look at the soil, it may seem like lifeless clay and rocks. But in fact the soil is very much alive. Many millions of small organisms live in healthy soil. Some of the organisms are big enough to see, such as earthworms and small insects. You can also see living roots in the soil, both tea roots and roots of other plants. But, most living things in the soil are so small that you can only see them if you use a microscope. These microscopic organisms include nematodes (tiny worms), bacteria, and fungi. Even some soil insects are so small that you can only see them with a microscope.



The Living Soil*: soil contains many small organisms like nematodes, fungi, and small insects. (Picture from Schoubroeck et al, 1989).*

What do soil organisms do? Some soil organisms can be called *neutrals* [translation: cac con binh thuong?], because they do not have a clear beneficial function in the agro-ecosystem, but they do not damage the crop. A few soil organisms actually *hurt* tea plants (for example, by causing root-rot diseases). Indeed, some pests that attack the above-ground parts of the plant (such as termites) can temporarily shelter or hide in the soil. But, *most soil organisms help the tea plant* by:

- Breaking down dead leaves and other plant debris, converting them into organic matter and making their nutrients available for the tea roots.
- Burrowing in the soil to make small tunnels that increase aeration and water movement.
- Causing tiny soil particles to stick together, opening up spaces that allow water and air to enter the soil more easily (see the drawing in Section 3.2, below).
- Protecting plant roots from harmful organisms.
- Serving as food for predators such as beetles.

The life in the soil helps the farmer. To keep the soil alive, it is important to:

1. ***Feed it through regular supply of organic material (= food for microorganisms).***
2. ***Protect it from erosion, for example by covering the soil (mulch or green manure).***
3. ***Reduce disturbing factors such as pesticides and high doses of chemical fertilizers.***

For more details about soil management, see Section 3.3 “Managing your soil”.

Related exercises

From CABI Bioscience/FAO manual: Exercise 2-A.4, entitled “The living soil”.

3.1.2 Soil includes non-living components

In addition to living organisms, soil is made up of:

- **Tiny pieces of rock** (pebbles, sand, silt, and clay) that we will call “particles”. These particles of rock make up most of the volume and weight of the soil.
- **Water,** found in three places: (1) Stuck to the surfaces of the particles of rock, (2) filling some of the spaces between the particles, and (3) stored in the organic matter as in a sponge. All the living things in soil, including plant roots, need water to live.
- **Gases** (oxygen, carbon dioxide, and others) in the spaces between the particles that are not filled by water. Plant roots, and most other living things in the soil, need oxygen to live. If the soil is flooded, and all the spaces in the soil are filled with water, most plants will die because their roots cannot get oxygen.
- **Dead organic matter that is still available as food for micro-organisms** (including dead pieces of plants, fresh manure, etc.).

- **Humus (old organic matter that has already been completely decomposed).** Even though humus is not available as food for micro-organisms, it is very important for storing nutrients and water.
- **Nutrients** (dissolved in the soil water, and also stuck onto the surfaces of the rock particles and the surfaces of the tiny pieces of humus). Nutrients are the useful atoms that plants need to grow. They include nitrogen, phosphorous, potassium, and many "micronutrients" such as sulfur and iron.
- **Hydrogen ions.** These are the "atoms" that affect how acidic the soil is (in other words, affect the pH of the soil). The more hydrogen ions there are, the more acidic the soil is (the lower the pH). Like nutrients, hydrogen ions are dissolved in the soil water, and also stuck onto the surfaces of the rock particles and the surfaces of the tiny pieces of humus.

In the next section (Section 3.2), we will discuss how these components (particles, humus, etc.) affect the behavior of the soil (for example, affect how much water the soil holds during a drought). Then, in Section 3.3, we will discuss how to manage the soil to make it as suitable as possible for tea.

Question for farmers:

Which of the components of soil can farmers change by their management practices?

Answer: farmers can directly change only four components of the soil:

1. Water (by irrigating, or by digging drainage ditches).
2. Fresh organic matter (by adding green manure, compost, or animal manure).
3. Nutrients (by adding fresh organic matter or chemical fertilizers).
4. Hydrogen ions (by adding lime or acidic fertilizers).

But, as we will see in the next section, when farmers add organic matter, they can indirectly affect many other soil components, including the living organisms, the hydrogen ions, and even the particles of clay. ***Managing organic matter is the key to managing the soil.***

3.2 *What soil properties are most suitable for tea?*

If you ask tea farmers what properties they want their soil to have, you will get answers that include the following:

- Soil is **deep**, at least 60 cm and better if more than 1 meter deep
- Soil is **rich in nutrients**, with a good balance among the different nutrients
- Soil is a bit **acidic**, with a pH suitable for tea (between 4.5 and 5.5)
- **Water enters** the soil easily during rains, therefore soil does not suffer much erosion
- **Soil stores a lot of water**, and slowly releases it to plant roots during dry weather
- Soil is well-drained; the underground water is at least 80 cm below the surface of the soil.
- **Soil is soft** enough to be easy to work, and easy for plant roots to penetrate
- **Soil is healthy**; organic matter breaks down rapidly, and plants do not get root-rot diseases or nematodes.

What causes soil to have these desirable properties? Of course, the answer is, the components of soil that were mentioned already (in Section 3.1). Farmers can change some components by management, but other components cannot be changed directly.

3.2.1 Soil depth

Everyone agrees: tea grows best on soil that is 1.5 meters deep or deeper. Soils this deep are rare in Viet Nam, but soil for tea should be at least 60 cm deep with subsoil at least 1 m deep. Slope must be less than 25°. If you are choosing new land for tea production, try to choose land that has deep soil and a moderate slope. But most tea farmers must use the land that they already have. Therefore, the only recommendation is to protect your soil from erosion so that it does not get any shallower. And, slowly build up your soil by adding manure, compost, or mulch.

3.2.2 Soil nutrient content

Most nutrients come from rocks. So, the soil in each field has a certain nutrient content that is "built into" the soil particles. In other words, some soil is naturally more rich in nutrients, and some less rich; it depends on the rocks from which each soil was formed.
In Viet Nam, the best soils for tea are:

- Gray ferralitic soil (soil scientists classify these as Acf Ferralitic Acrisols)
- Gray humus soil in mountainous areas (soil scientists classify these as Acu Humic Acrisols)

According to several surveys, there are many areas in the northern mountainous areas of Viet Nam that have soils suitable for tea production. These soils were developed from the following kinds of "parent" materials. So, areas where these "parent" materials are found are likely to have good tea soils:

- Slate (including Mica slate, Agrillaceous slate, and Sandstone slate)
- Sandstone
- "Gnai" soil
- Ancient alluvial soil (carried by ancient rivers)
- Valley-filling soil

If you are choosing new land for tea production, try to choose land that has ferralitic or gray humus soil that was formed from one of the "parent" materials listed above. But, most tea farmers must use the land that they already have, which may not have enough nutrients. Further, plants <u>remove</u> nutrients from the soil in order to grow and produce a crop. Nutrients are also lost through erosion, leaching and immobilization. The loss of nutrients to leaching is a particular problem in the acidic tea soils (see the section on soil pH, below, for more information).

Fortunately, farmers can add additional nutrients to the soil, to compensate for this loss of nutrients. Farmers can add nutrients in the form of organic materials, chemical fertilizers, or a combination. The importance of using organic fertilizer is strongly emphasized in this guide.

A well-balanced amount of available nutrients results in healthy plants. A healthy plant can resist pests and diseases better. Well-balanced fertilization is not the same as excessive

fertilization! For example, too much nitrogen is known to increase disease occurrence in crops! Also, adding too much chemical fertilizer may simply be a waste of money.☹
Organic fertilizers such as compost or green manure release nutrients slowly. Therefore, they require the farmer to plan ahead. If you wait until the plant is suffering from a nutrient deficiency, it is too late to apply organic fertilizers.

Analogy: When we choose food for our children, the best strategy is not to worry about providing this or that specific nutrient, and trying to evaluate this or that nutrient deficiency. Rather, we make sure to provide them with a balanced diet (fruits, green and yellow vegetables, meats and fish, rice, etc.). Similarly with the soil, the best strategy is to make sure the soil has a "balanced diet" by replenishing the extracted nutrients through the application of organic matter. Source of the analogy: William Settle, "Living soils: Training exercises for integrated soils management". FAO Programme for Community IPM in Asia, June 2000.

Macro and micronutrients

Macronutrients are nitrogen (N), phosphorus (P) and potassium (K). These are nutrients that all plants need in relatively large amounts. *Micronutrients* are just as essential for plant growth, but required in smaller quantities than N, P, and K. Micronutrients include calcium, sulfur, magnesium, boron, copper, iron, manganese, molybdenum, zinc, and chlorine. Organic material usually contains both the macronutrients N, P and K and micronutrients. Because they are needed only in small quantities, micronutrients should be applied only when a clear deficiency is indicated. **See Chapter 6 for specific recommendations about fertilization needs of tea.**

Some of the micronutrients are found in the mineral particles of the soil but most come from the breakdown of organic matter. The micronutrients exist in very complex forms and have to be broken down into simpler forms that the plant roots can absorb. This process is comparable with the breakdown of leaves in the soil: slowly they will become soft, fall apart into very small pieces and eventually disappear. This breakdown process is done by microorganisms, mainly bacteria that live in the soil. That is why it is important to stimulate the biological activity in the soil: it results in better soil fertility! To function effectively, the microorganisms need air, water, soil that is not too acidic (pH 6 or higher is best for them), and <u>lots of organic matter</u>.

Soil testing

The amount of fertilization to be added depends on the amount of nutrients already available in the soil. A soil-testing service can be a good way to find out how much nutrients needs to be added. In some countries, the Department of Agriculture provides a soil-testing service. There are also portable test kits that can examine the main nutrients of the soil. Results and reliability of these portable kits however vary.

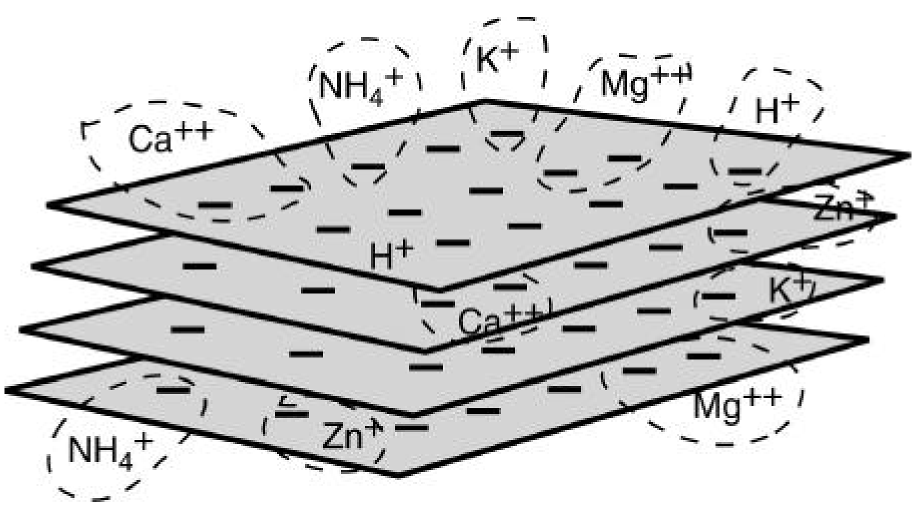
The test kits are useful to find deficiencies of N, P and K. But recommendations for the amount of fertilizer to apply depend on local soil conditions. For example, past field history should be considered when interpreting soil test results. This is particularly important when the farmer has applied a lot of organic matter in the past. Because the organic matter releases nutrients slowly, the soil tests may under-estimate the amount of soil nutrients actually available to plants over the course of the entire season. Another limitation is that soil testing usually does not provide information about soil structure or biological activity, although some estimate of soil organic matter can be included.

Another way to get information about possible soil imbalances is by carefully digging up a plant, shaking off the soil, and examining the roots for vigor and signs of disease or pest damage. In general, roots growing in a fertile soil are more branched than in a poor soil, and they have a profusion of root hairs. However, the plants must be dug up very carefully to avoid losing the root hairs. If the roots are growing horizontally and are long and stringy, then they are searching for nutrients. If they are long, seem to be searching for something but grow vertically, they need water. If they are growing only near the surface, the soil is too wet. If they are thick and short they may be suffering from a toxic element, or a disease.

3.2.3 Ability of soil to store nutrients

As was discussed above, nutrients are released either when chemical fertilizers dissolve, or when organic matter decomposes. If the soil cannot store the nutrients, they will be washed away by water before the tea roots can absorb them. The soil stores nutrients in two places: stuck to the surface of clay particles, and stuck to the surface of humus (decomposed organic matter).

Clay particles and humus store nutrients because they have many negatively charged “parking places” in which the positively charged nutrients (e.g., Mg++, Zn+, NH4+, Ca+, etc.) can be “parked”. How can farmers increase the number of “parking spaces” in their soil? Farmers cannot add more clay to their soil. But, they can add more organic matter, and therefore increase the ability of the soil to store nutrients.



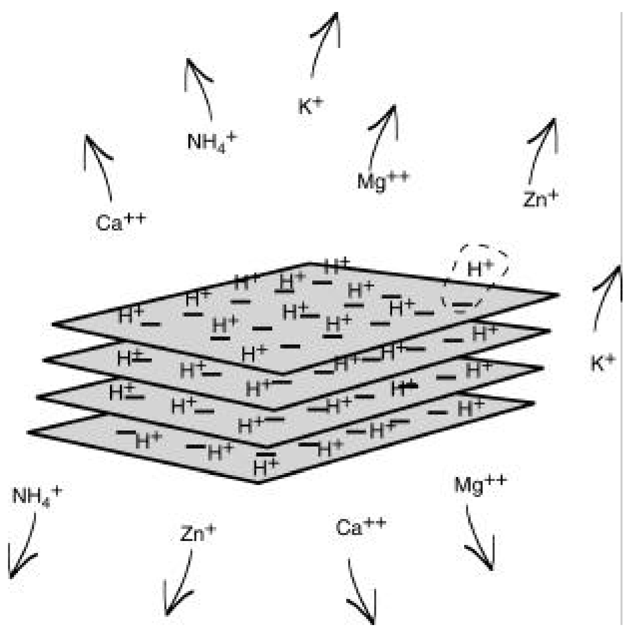
Temporary storage of nutrients in "parking spaces" stuck to the surface of a clay particle. Source of the drawing: William Settle, "Living soils: Training exercises for integrated soils management". FAO Programme for Community IPM in Asia, June 2000.

3.2.4 Soil acidity (pH)

Tea requires soil that is more acidic than is suitable for many other crops. The best pH for tea is between 4.5 and 5.5 (never below 4.0 or above 6.2).

Soil pH affects the ability of the soil to release nutrients. If the pH level is too high or too low, nutrients can get "locked up" in the soil and become unavailable to plants. For example, if the pH is too high, then the iron in the soil will not be available to the tea roots. The soil pH can also influence plant growth by its effect on activity of beneficial microorganisms. Beneficial fungi can tolerate slightly acid soils, but bacteria that decompose soil organic matter are hindered in strong acid soils. This prevents organic matter from breaking down, resulting in nutrients (especially nitrogen) being “locked up” in un-decomposed organic matter.

Strongly acid soil also causes the rapid loss of soil nutrients. The reason is, clay particles and humus store positively-charged nutrients in negatively charged “parking places”. If, however, the soil water is highly acidic (too much H+), then the H+ ends up filling up many of the “parking spaces”. If that happens, some of the nutrients that would normally be stored on the surface of the clay particles are lost (washed away to a lower level in the soil profile).



Excess acid (hydrogen ions) pushes nutrients out of the "parking spaces" on the surface of a clay particle. Source of the drawing: William Settle, "Living soils: Training exercises for integrated soils management". FAO Programme for Community IPM in Asia, June 2000.

The soil in each field has a natural pH that is “built into” the soil particles. This is because some rocks are more acidic than others. In other words, some soil is naturally more acidic, and some less acidic; it depends on the rocks from which each soil was formed.

Because pH is “built into” the soil particles, there is no way to change it permanently. But fortunately, farmers can temporarily change soil pH by adding organic matter, adding lime, or adding acidic fertilizers. Some of these methods are discussed in more detail below. However, it should be noted that correcting the soil pH is a process that takes time - sometimes a few years!

What does pH mean, and how can you measure it?

An important factor in soil is whether it is *acid* or *alkaline*. This is measured in the form of a pH value. The “H” in pH stands for hydrogen ions. pH is a measure of how many free hydrogen ions are found in a liquid (for example, in the water stored in a soil).

These pH values range from 1 to 14. Soil with a pH of around 7 is neutral. If the pH is less than 7 it means that the soil is acid (many hydrogen ions). If the pH is greater than 7, the soil is alkaline (few hydrogen ions).

The pH scale*:

very acidic		neutral		very alkaline	
1		7		14	
many free hydrogen ions		balance between H+ and OH-		few free hydrogen ions	
H+	OH-	H+	OH-	H+	OH-
H+	OH-	H+	OH-	H+	OH-
H+		H+	OH-		OH-
H+		H+	OH-		OH-
H+		H+	OH-		OH-
H+		H+	OH-		OH-

The easiest way to measure soil pH is with two types of special paper (one colored pink, the other blue). First, mix a little water with some soil. Then, put a drop of the mixture on the papers. The color of the paper will change according to how acidic the mixture is. By comparing the color to a chart, you can get a rough idea of the pH. pH can be measured more precisely with a soil testing kit that uses liquid chemicals and a color comparison, or with a pH meter (a small machine). If you send a sample of soil to a soil-testing laboratory, they usually test the pH of your soil with a pH meter.

* Diagram of pH scale modified from: William Settle, “Living soils: Training exercises for integrated soils management”. FAO Programme for Community IPM in Asia, June 2000.

1. Adding organic matter is the longest-lasting solution to extreme pH

Humus, the black substance that comes from the break-down of organic matter, acts like a “shock absorber” to regulate soil pH. Humus itself is neutral and can absorb either acid and alkali “shocks” (for example, caused by application of chemical fertilizers). Application of lots of organic matter into soils is a good and more permanent solution to neutralize soil pH than the application of lime. However, soils with very high or very low pH should also receive sulfur or lime (see below).

2. To raise the pH of very acidic soils, add lime

Soils tend to become acidic as a result of:

1. Rainwater leaching away basic ions (calcium, magnesium, potassium and sodium),
2. Carbon dioxide (CO_2) from decomposing organic matter and root respiration dissolving in soil water to form a weak organic acid;
3. Formation of strong organic and inorganic acids, such as nitric and sulfuric acid, from decaying organic matter and oxidation of ammonium and sulfur fertilizers. Strongly acid soils are usually the result of the action of these strong organic and inorganic acids.

The soil pH can be raised by applying lime or wood ashes. Unless you have access to large amounts of wood ash, you will probably need to use lime. In addition to raising the pH, lime:

- Provides two nutrients, calcium and magnesium, to the soil
- Makes phosphorus that is added to the soil more available for plant growth
- Increases the availability of nitrogen by speeding up the decomposition of organic matter.

Types of lime

There are several types of lime available to raise pH. *Hydrated lime*, which is quick acting, should be applied several weeks prior to planting and watered in well to avoid any chances of burning the crop. *Crushed limestone* is much slower acting but longer lasting in its effect. It requires a heavier application but can be used with less chance of burning. *Dolomite limestone* is a special type of crushed limestone. Dolomite is particularly good because it contains the trace element magnesium, which is an essential fertilizer element for plants. Wood ashes can also be used to increase soil pH.

There may be many other types of lime in your area. Check with the provider how quickly it acts and how it should be applied.

The timing of lime application is quite critical as it takes a while before the lime decomposes and the pH goes up. The amount of time depends on the type of lime used, soil humidity, and temperature. If you are planting a new field, the general rule is that lime should be applied and worked into the soil about 4 weeks before planting. It is also good to make sure the soil is moist when applying lime, or water immediately after applying.

The amount of lime needed to correct a soil acidity problem is affected by a number of factors, including soil pH, soil type (amount of sand, silt and clay), structure, and amount of organic matter. This is shown in the following table:

BE CAREFUL! This table shows the amount of lime needed to raise the pH to 6.5, which is much higher than is suitable for tea. To raise the pH to 5.0 or 5.5, use less lime than shown in the table.			
Soil pH before adding lime	**Lime required (kg/ha) to raise to pH 6.5**		
	Soil type: Sand	Soil type: Loam	Soil type: Clay
6.0	1000	1700	2400
5.5	2200	3700	4900
5.0	3200	5400	7300
4.5	3900	7300	9700
4.0	4900	8500	11200

☞ As always, you should do an experiment on a small part of the field to see how much lime you need. Use study #2 from the Tea IPM Field Guide as a guide (study entitled "Yield, pest and natural enemy, and disease response to type of fertilizer"). Instead of different types of fertilizers, use different types and amounts of lime. In your experiment, measure the change in the soil pH, but also measure the cost and economic benefit of the lime. Did your tea yield or quality improve as a result of applying lime? Remember, it may take many months before the lime produces its full effect.

Also, ask nearby farmers and extension personnel how much lime they have used in the past. Did their tea yields or quality improve?

Lime for control of soil-borne diseases?

In some areas, lime is applied to the field for disease control. Lime may change the micro-environment in the soil somewhat, resulting in changes the population of microorganisms, including pathogens. It may also have an effect on general crop health: by raising the pH, other nutrients become available, plants may grow better and stronger plants can resist diseases better. Set up an experiment to see what the effects of applying lime would be in your situation.

If you have problems with root-rots, it is recommended to apply lime to the planting hole while transplanting. Dig up and burn any infected bushes or trees. Carefully check the neighboring bushes, and dig up and burn any that are infected. Remove and discard the soil closest to the roots of the infected bushes. Expose the hole to the sun, then treat the hole with lime and wood ashes to help kill the root rot remaining behind. Then, re-plant with healthy tea seedlings.

3. To lower the pH of very alkaline soils, add sulfur

Sulfur dissolves in the soil water to produce sulfuric acid, which releases many hydrogen ions and therefore lowers the pH. To lower pH, sulfur is usually added in the form of aluminum sulfate. A more-expensive but more-effective alternative is pyrite (ferrous sulfate). These two chemicals (aluminum sulfate and pyrite) are not truly fertilizers; they are tools for lowering pH. Their advantage is that they have a relatively fast effect on the pH (within 6-12 months).

An alternative is to use acidic fertilizers, especially ammonium sulfate, which provides nitrogen. Ammonium sulfate will decrease the soil pH, but much more slowly than aluminum sulfate (must be used for several years). The advantages and disadvantages of these three chemicals are summarized in the following table:

	Aluminum sulfate	**Pyrite (ferrous aluminum)**	**Ammonium sulfate**
Advantages	Fast action (6-12 months) More effective than ammonium sulfate	Fast action (6-12 months) The most effective (less quantity needed)	Provides nitrogen
Disadvantages	Does not provide nitrogen	Does not provide nitrogen The most expensive	Slow action (several years) The least effective

To figure out how much sulfur to apply, you should do an experiment. Use study #2 from the Tea IPM Field Guide as a guide (study entitled "Yield, pest and natural enemy, and disease response to type of fertilizer"). Instead of different types of fertilizers, use different types and amounts of sulfur chemicals. The amount of sulfur to use depends on the pH of your soil. The higher the soil pH, the more sulfur you should add. The amount of sulfur also depends on the soil texture. Stiff, clayey soils require more sulfur than sandy soils. To help you plan your experiment, here are some results from India using aluminum sulfate and pyrites:

Chemical	Amount applied	Soil pH			
		Before applying		9 months after applying	
		Topsoil	Subsoil	Topsoil	Subsoil
Aluminum sulfate	4 tons / ha	5.9	6.1	5.3	5.5
	8 tons / ha			5.0	5.1
Pyrites	4 tons / ha	5.9	6.1	4.4	4.9
	8 tons / ha			4.2	4.5

To calculate how much acidic fertilizer to use in your experiment, use the procedure for calculating quantities of nitrogen fertilizers that is explained in Chapter 6. For the calculation, you will need to remember that ammonium sulfate contains 21% nitrogen. For example, experiments in India used 600 kg / ha of ammonium sulfate each year for two years.

3.2.5 Water entry and storage

A good soil can be compared with a new sponge: water enters easily, and remains stored inside for later use. The ease with which water enters the soil, and is stored in the soil, is determined by two soil properties: *texture* and *structure*. Adding organic matter will improve the water entry and water storage of any soil.

Soil is a mixture of different-sized particles:

- **sand** (the largest particles, with diameters from 2 mm down to 0.05 mm)
- **silt** (with diameters from 0.05 mm down to 0.002 mm)
- **clay** (the smallest particles, with diameters less than 0.002 mm).

The percentages of sand, silt, and clay in the soil is called the "texture" of the soil. For example, a soil might be 40% sand, 25% silt, and 35% clay. Different names are given to soils with different textures. In general, soil that contains a lot of sand is called "coarse-textured" or "light" soil. Soil that contains a lot of silt and clay is called "fine-textured" or "heavy" soil. More specific names can be used to describe soil textures, such as sand, sandy loam, loam, clay loam, etc. These names indicate the different percentages of each size of particle (sand, silt, and clay) in the soils.

The texture of a soil determines the ability of the soil to absorb water, store water, and store nutrients needed by plants. Texture also determines the ease with which plant roots can penetrate the soil. This is summarized in the following table:

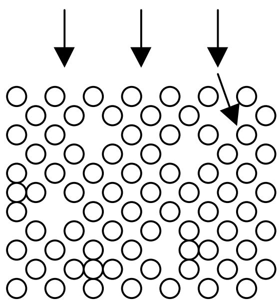
	Advantages	**Disadvantages**
Sand (light soils)	Good movement (of water, nutrients, and roots)	Poor storage (of water and nutrients)
Clay (heavy soils)	Good storage (of water and nutrients)	Poor movement (of water, nutrients, and roots)

Tea can tolerate a wide range of textures. For example, some tea soils in India contain up to 40% stones and pebbles, while some tea soils in eastern Africa contain up to 80% clay. But the best soil texture, called "loam", has about equal amounts of sand, silt, and clay. This texture has enough sand to allow water to enter and move easily in the soil. And, it also has enough clay to retain and store large amounts of water. If you are choosing new land for tea production, try to choose land that has soil that contains not just clay, but also substantial amounts of sand and silt.

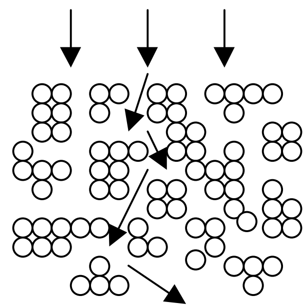
Most tea farmers must use the land that they already have. If their soil has too much clay, it can store large amounts of water, but water cannot enter easily (rain runs off the soil surface and causes erosion). Or if their soil is sandy, water will enter but will not be stored. In a large field, ***farmers cannot improve soil texture.*** This would require bringing in truckloads of sand (or clay) to change the proportions of the different-sized particles.

Fortunately, ***farmers <u>can</u> improve soil structure.*** The term "*structure*" refers to the arrangement of the soil particles into aggregates (very small clumps). Soil aggregates are about the size of sand grains (from 0.25 mm to 5.0 mm in diameter). Aggregates are formed when clay and silt particles stick together. This improves the soil, because it creates pores (open spaces) between the aggregates (see the picture, below).

Bad soil structure:
Water cannot enter easily when tiny soil particles fill up most of the spaces.



Good soil structure:
Water can enter more easily when tiny soil particles stick together to form aggregates, leaving some empty spaces (pores).



Only the *structure* is different between the two pictures. The *texture* (percent of small particles) is the same in both pictures.

Analogy: a particular building is made of bricks. The "texture" of the building would be the proportion of cement, sand and brick (clay, silt and sand) that comprises the whole building. The "structure" of the building would be the arrangement of these bricks to form large rooms, small rooms, hallways, closets, etc. If an earthquake should cause the building to collapse into a pile of bricks, the "texture" would remain the same, but the "structure" would have been radically altered.

To follow on our analogy, just as before the earthquake the "structure" of the building provided much better living conditions than after (big and small rooms in which to move and live), similarly, a soil that has a good structure has many large and small pore spaces through which air, water, roots and living organisms can move freely.

Source of analogy: William Settle, "Living soils: Training exercises for integrated soils management". FAO Programme for Community IPM in Asia, June 2000.

In the pores between the aggregates the soil air is found, an important source of oxygen for root respiration. Like humans, most plants and their roots need air (oxygen) for respiration. Also, the pores between the aggregates hold water. A good soil structure permits the movement of air and water through the soil, helping the development of a good root system.

How can farmers improve soil structure? By adding organic matter, either well-rotted compost or fresh organic matter. Well-rotted compost contains *humus*, which acts like glue to bind together soil particles. And fresh organic matter provides food for living organisms, which themselves improve the soil structure:

- **Small insects and (especially) earthworms** play an important role in improving soil structure. Their movements and feeding behavior leave pore spaces and help "cement" together particles into aggregates.
- **Fungi** grow on organic matter, creating a "spider web" of fungal branches that holds soil particles together.
- **Bacteria** produce gums that glue together soil particles into aggregates.

Adding organic matter improves the structure of heavy (clay) soil. This solves the problem of water not being able to enter easily. Adding organic matter also improves the structure of light (sandy) soils. Sandy soils have the problem of not being able to <u>store</u> much water. Organic matter (especially well-rotted compost and humus) coat the sand grains and store large amounts of water just like a sponge.

Related exercises from CABI Bioscience/FAO manual:

2-A.3. Soil structure and effects on root growth
2-A.8. Soil test kits

3.2.6 Drainage and depth of underground water

As was discussed above, water should enter the soil easily, and be stored by the soil. But tea also requires "dry feet". If the soil around the tea roots is too wet for too long, tea roots will not be able to breathe, and will die. Therefore, excess water must be able to drain away into the very deep soil.

Deep in the ground, the soil is completely saturated with water. You can think of this as an underground lake; it is this "lake" that you access by digging a well. The distance from the top of the soil to the top of the underground lake changes from place to place (for example, some villages have deeper wells than other villages). Also, the distance changes from one season to the next; the lake usually sinks deeper into the ground during the dry season.

Tea grows best in areas where the underground water is always about 80-100 cm below the surface of the soil. If you are choosing new land for tea production, try to choose land where the underground water does not come too close to the surface. But at the same time, avoid land where the underground water is too deep. If the underground water is too deep, then the roots of tea bushes and shade trees will not be able to reach it during droughts.

How to estimate the depth of the underground water

This method was recommended by an extension worker from Thai Nguyen. We have not tried it ourselves. If you try it, then please send us a letter describing your results.

To estimate the depth of the underground water:
1. Borrow a bowl (ceramic or metal) from someone's kitchen.
2. Dig a hole in the field where you want to check the depth of the water. The hole should be about the same diameter as the bowl, and be at least 1 m deep.
3. Put the bowl in the hole at the depth that you want to test (say, about 80-100 cm deep). The open end of the bowl should be pointing downwards, towards the soil. Leave the hole open (do not bury the bowl in soil).
4. Leave the bowl in the hole overnight. The next morning, carefully remove the bowl and check to see if any drops of water are clinging to the inside of the bowl. If the soil was wet enough to produce water inside the upside-down bowl, then the underground water probably comes up to the depth at which the bowl was sitting.

That's how they do it in Thai Nguyen!

3.2.7 Ease of working the soil

"Working the soil" means any activity where the soil must be moved (such as digging holes for planting seedlings, pulling weeds, making terraces, etc.). As was discussed in the previous section, the ease of working the soil is determined by its texture. Coarse-textured soils with lots of sand are easy to work. Fine-textured soils with lots of clay are hard to work, because they absorb a lot of water. This makes them heavy and sticky.

Again, ***farmers cannot improve soil texture.*** This would require bringing in truckloads of sand to make the soil more coarse. But, ***farmers can improve soil structure*** by adding organic matter. The organic matter causes the tiny clay particles to stick together, forming aggregates that are about the size of sand grains. The result is that the soil drainage improves and the soil becomes easier to work. For more information about how organic matter improves soil structure, see Section 3.2.5 (above).

3.2.8 Soil health

Preventing soil diseases

Next to the beneficial decomposers or neutral organisms in the soil, soil may also contain organisms that are harmful to the crop. These include insects and pathogens like fungi, bacteria and nematodes. Soil-borne pathogens can enter a field in numerous ways. They may be attached to pieces of soil on the roots of seedlings, to soil particles on tools used in several fields, or with bits of soil on your slippers or shoes. They may also be spread with water.

Pathogens are so small that they cannot be seen with the unaided eyes. Only when they affect the plants do they become apparent. At that point, some injury to the plants has already occurred. And, maybe even more important, once there is a disease in the soil of the field (soil-borne disease), it is very difficult to get rid of it. Many pathogens can survive for a long time in the soil, even without a host plant! Therefore, it is essential to prevent soil-borne diseases from entering the field and attacking the plants. See box below.

***Preventing* soil-borne diseases: some techniques.**

Preventing soil-borne diseases is not a single action, there are several factors involved. Some of the main activities include:

1. Crop rotation
2. Use of clean seed or clean cuttings
3. Use of clean soil in nurseries.
4. Sanitation practices such as:
    - removing roots of forest trees before planting a new field,
    - removing weeds,
    - cleaning field tools.
5. Increasing soil organic matter content (increasing organic matter of soil can increase microbial activity, which can lower population densities of soil-borne pathogens).
6. Proper water management: mainly providing drainage to keep soil around roots from becoming waterlogged.
7. Application of antagonistic fungi such as *Trichoderma* sp. into the soil (see Section 11.4.1).

Antagonists (natural enemies of pathogens)

Microorganisms in the soil promote soil health. Species of those microorganisms may include antagonists such as the fungus *Trichoderma* that can control several species of fungi that cause damping-off disease in nurseries. *Trichoderma* occurs naturally in many soils but can also be applied (see Chapters 10 and 11). There are many other useful antagonistic fungi and bacteria occurring naturally in soils. **To build up the numbers of useful microorganisms, feed them by adding organic matter to the soil.** Organic matter can be added using various methods: compost, cover crops, green manure, mulch, etc.

Beneficial microorganisms are especially abundant in compost. Therefore, in addition to its value as a fertilizer, compost can reduce disease problems for plants. This has been studied for several years now because it offers an opportunity to further reduce fungicide use.

Scientists describe two different types of disease suppression in compost and soil:

1. General suppression is due to many different microorganisms in the compost that either compete with pathogens for nutrients and/or produce certain substances (called *antibiotics*) that reduce pathogen survival and growth. Thus an active population of microorganisms in the soil or compost outcompetes pathogens and will often prevent disease.

This type of suppression is effective on those pathogens that have small spores. The reason is, small spores do not contain many nutrients. In other words, pathogens with small spores must compete with other soil microorganisms for the available carbon (organic matter) in the soil. Examples of this mechanism are suppression of damping-off and root rot diseases caused by *Pythium* species and *Phytophthora* species.

2. **Specific suppression**, on the other hand, is usually the result of only one or a few beneficial organisms. These specialized biocontrol agents either parasitize the pathogen, or induce systemic resistance in the plant to specific pathogens, much like a vaccination. Pathogens such as *Rhizoctonia solani* and *Sclerotium rolfsii* are examples where specific suppression may work but general suppression does not work. This is because these pathogens have large spores with lots of nutrients, and thus are less susceptible to microbial competition. Specific natural enemies such as the fungi *Trichoderma* and *Gliocladium* species will colonize the spores of pathogens and reduce disease potential.

Other biocontrol agents (or antagonists) that colonize composts include bacteria like *Bacillus subtilis*, *Enterobacter*, *Flavobacterium balusstinum*, and *Pseudomonas*; and actinomycetes like *Streptomyces.* These antagonists may appear naturally in compost. In some cases, antagonistic fungi or bacteria are added to the compost just after the hot phase, when the compost is cooling down. There are not much microorganisms present inside the compost at that moment. When antagonists are added at that time, they can quickly build up their populations and this will result in compost with good disease suppressing quality. See box below.

Fortified composts

An interesting option is the use of *fortified* compost. This is compost added with antagonistic organisms such as the *Trichoderma* fungus. Such fortified composts provide nutrients to the crop (through the compost) and they provide effective control of a range of plant pathogens (mainly through the antagonistic fungi). After the primary heating period of composting is complete, the *Trichoderma* is added to the compost. The fungi increase to high levels in the compost and can effectively reduce diseases caused by *Rhizoctonia solani*, and species of *Pythium, Phytophthora* and *Fusarium*.

In order for compost to substitute for currently used fungicides, the disease suppressive character must be consistent and somewhat quantifiable to reduce risk for the farmers. There are specialized compost companies that produce consistently suppressive composts, especially for the nursery industry. To help control quality, in the USA, fortified composts must be officially registered.

Compost quality plays a role in the degree of disease suppression and the length of suppressive activity. Some general observations:

- Compost that is allowed to mature is more suppressive than when used straight after the hot phase.
- Compost piles that are in the open (so exposed to naturally occurring microorganisms), and especially those located near trees, are more suppressive than compost piles sheltered by a roof.

Professional nursery industries now use disease-suppressing compost widely and routinely. Based on the successes there, researchers are testing compost on a number of field crops for potential disease suppression. Results of several studies are very promising. For example, studies in California, U.S.A., showed that soils on organic farms (using lots of compost) were more suppressive to two tomato diseases than soils from conventionally managed farms, due to differences in soil organic matter, population of microorganism, and nitrate level. Other researcher report less disease (even foliar disease such as early blight in tomato), dramatic reductions in rootknot nematode damage, and higher yields on composted plots compared to conventional treatment in several crops. In addition, several investigators are testing the use of compost teas as a foliar spray to prevent and control leaf diseases. For more information on compost teas, see Chapter Ten.

Soil sterilization

Once the soil is infected with a pathogen, there are few options for control/management. The best is to reduce the pathogen population with methods like crop rotation. For example, planting grass for a few years to control soil diseases is discussed in Chapter Five.

For smaller field sizes, such as nurseries or when re-planting a small area, it is possible to use non-chemical methods to sterilize soil. Such methods include solarization or burning plant materials on the soil. These and other methods are described in Chapter Five on nursery management.

It is dangerous to use non-specific chemicals for soil sterilization. Such chemicals are not always effective because pathogens may live deep in the soil, or be protected inside plant debris, where chemicals do not reach. In addition, residues of pesticides in the soil may cause damage to the next crop and residues may leach into ground and surface water causing death of fish, problems with drinking water, and cause damage to microorganisms in the soil and the aquatic ecosystems in general.

3.3 How to manage your soil

Many farmers are concerned about how to keep or restore soil fertility in order to maintain good yields. Too often, the emphasis is on adding nutrients, but not so much on protecting soil through soil conservation. But actually, fertilization and soil conservation are equally important. Nutrients are linked with chemical qualities of the soil, while conservation also emphasizes the physical and biological characteristics of soil. Conservation is not only preventing soil from being lost to erosion, but also keeping a good soil structure and stimulating the activity of microorganisms in the soil.

3.3.1 The role of organic matter and microorganisms

One of the most important ways to improve chemical, physical, and biological characteristics of the soil is to add organic matter. Organic matter can be added as compost, cover crops, green manure, or organic mulch. Some of the benefits of organic matter include:

1. Organic matter increases the biological activity of soil

Adding organic matter provides food for the many small beneficial organisms that live in the soil. Soil that has received organic matter has more abundant and more diverse microbial populations. These organisms make nutrients available to plants by decomposing organic matter and releasing nutrients (mineralization). In other words, organic material is food for microorganisms, and these microorganisms then produce food for the tea plants.

2. Organic matter stores and slowly releases nutrients

The long-term objective of adding organic matter is to build up soil humus. Humus is the more or less stable fraction of the soil organic matter remaining after decomposition of plant and animal residues. Humus is valuable for its ability to hold nutrients in an available state. Soils that are rich in organic matter are a good source of nutrients over a long period of time, as the nutrients from the organic material will be released gradually. *If sufficient organic matter is supplied regularly to the soil, usually no chemical fertilizers need to be applied.*

3. Organic matter improves water movement, aeration, and ease of working the soil

Organic matter improves the structure of the soil, both directly and indirectly. The direct effect is from the spongy humus. The indirect effect is from the bacterial gums and fungal threads produced by microorganisms that feed on the organic matter. Humus, gums, and threads work together to bind together tiny soil particles, creating spaces for the movement of air and water.

4. Organic matter promotes soil health

Microorganisms in the soil protect roots from disease by competing with or parasitizing pathogens. Natural biocontrol agents include antagonists such as the fungus *Trichoderma* that can control several species of fungi that cause root-rot disease. *Trichoderma* occurs naturally in many soils but can also be applied (see Chapters 10 and 11). Many other useful antagonistic organisms occur naturally in soils. They are particularly abundant in compost.

3.3.2 <u>Some principles of soil conservation and fertilization</u>

(modified from Murakami, 1991):

1. Keep the soil covered

When soil is uncovered, it is easily attacked by rain, wind and sun heat. This is the main cause for degradation of soil structure and soil erosion. During growth of a crop in the field, the soil can be covered by a mulch (such as rice straw) or a “living mulch” which is a crop that grows together with the main crop but is not harvested (for example, green manure crops). When no production crop is planted in the field, consider sowing a cover crop. This will keep the soil covered and thus protected from erosion by wind or water and it is a very good way of fertilizing the soil.

2. Feed the soil a regular supply of organic material

Adding organic material to soil is essential for good crop production! Organic matter such as compost can supply all necessary nutrients to plants, and helps maintain a balanced pH. Organic matter also stimulates the activity of beneficial microorganisms in the soil. Microorganisms help release nutrients from organic material in the soil, help improve soil structure, and help protect roots from diseases.

3. Maintain vegetation on field or farm boundary areas

Another useful practice is to plant trees and grasses in boundary areas of a farm. Such vegetation protects soil from run-off by rain and wind, it becomes a source of organic fertilizer, fodder, fuel, food (fruits), or timber and it also acts as a windbreaker. When flowering plants are used, they may attract natural enemies such as hover flies, and provide shelter for natural enemies such as spiders.

4. Eliminate the use of pesticides on soil

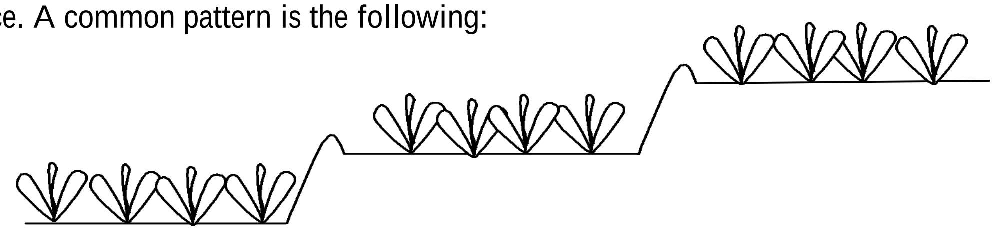
Pesticides disturb the activity of microorganisms in the soil and may create imbalances in soil fertility.

5. Reduce the use of chemical fertilizers; use organic fertilizers instead

When large amounts of organic material are supplied to the soil every year, usually no chemical fertilizers need to be added. Chemical fertilizers may create an imbalance in the soil ecosystem. They disturb the activity of microorganisms by adding only a few nutrients. In addition, nutrient supply has been known to cause disease problems in plants. Nonetheless, in some cases it can be good to use a small amount of chemical fertilizer (for example, nitrogen) to push plants through a stressful period such as when they are recovering from pruning.

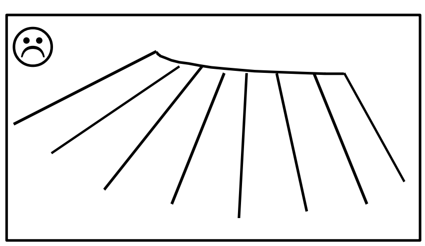
6. Build terraces on steep slopes

On steep slopes, building horizontal terraces is a common and good practice to prevent soil erosion. Often, a small "dike" is made (or a row of weeds is allowed) at the border of a terrace. A common pattern is the following:

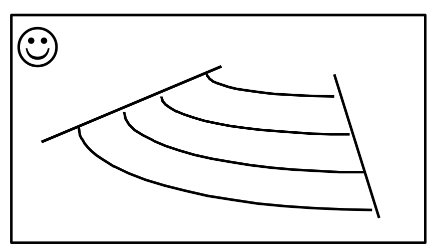


7. Plant along the gradient of the slope

On slopes without terraces, it is recommended to plant the rows of tea along the gradient of the slope. When rows are planted top-down, rain and irrigation water flow down hill and may take nutrients, soil particles and organic matter down. Those valuable matters are then lost for the crop. Also, water flowing down the hill can easily spread soil-borne diseases like root-rots or nematodes into the lower parts of the field.



Top down planting stimulates erosion...



... plant along the gradient of the slope!

Related exercises from CABI Bioscience/FAO manual:
2-A.2. Soil conservation: why?