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The U.S. Government's Global Hunger & Food Security Initiative



SOIL AND WATER CONSERVATION FOR SMALL FARM DEVELOPMENT IN THE TROPICS

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Soil and Water Conservation for Small Farm Development in the Tropics

R0084

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Intended for Peace Corps Volunteers working in agriculture projects, this manual addresses the many problems faced by small farmers in developing countries with tropical climates.

Easy-to-follow explanations of basic soil management principles and appropriate tools in the absence of more sophisticated alternatives are provided. The manual draws upon such publications as *Soils, Crops and Fertilizer Use* (ROO08) and *Soil Conservation Techniques for Hillside Farms* (R0062). It is also a useful source for technical trainers.

As populations continue to rise across the globe, the world's resources of food and water are becoming stressed beyond their limits. About 20 centimeters of topsoil covering the earth's crust produces the food that keeps us alive. This vulnerable topsoil is rapidly washing and blowing away. As more people need food, water, fuel, and shelter, they destroy vegetative cover and decimate forests, escalating topsoil loss and water runoff.

Our water supplies are also suffering an alarming depletion. Aquifers of some nations are just a decade from exhaustion. Many rivers and streams are dwindling, while others continue to fill with silt. Desert areas are also spreading, resulting in drought and starvation.

Most of this dire news is a result of misuse, overuse, and lack of proper husbandry or conservation. However, the situation is not hopeless.

Focusing on the small tropical farmer, this manual also helps Volunteers take advantage of improved technologies and aids them in providing demonstrations that can spread from one farmer to another. Small subsistence farmers are often pressured into farming poor quality land just to live. They eke out livings on steep slopes that are subject to excessive water runoff and soil erosion. They clear several millions of hectares of forested hillsides for farmland each year. Such land often soon becomes degraded and unfit for use.

This manual directly addresses such problems. As we all know, farmers learn from farmers and a demonstration on one farm that greatly increases yields and conserves soil and water will motivate other farmers to duplicate such successful measures.

The appropriate technologies described in this manual can increase crop production and conserve soil and water at the same time. The result can be sustainable farming systems that will enhance the health and welfare of millions of farm families.

Ch 1: Soil- The Sustainer of Life

Introduction

A nation's welfare nearly always depends ultimately on its soil—rocks determine the nature of our soils; soils determine our food; and the quality of food determines the health of our bodies.

Great civilizations remained great only as long as their soils remained fertile. Dense human populations developed where fertile soils existed. Even today, lifelines extend around the world to connect rich soils with large cities needing food.

The diversity of soils makes for wide variations in the yield and the quality of one's crops growing on them. Nation's soils are the starting point for the formulation of any policy that leads to lasting agricultural development.

This section provides an overview of soil, what it is made of, what its functions are, how long it takes to make it, factors affecting its formation, and its relationship with air, water, and plants.

Soil Defined

Soil is the outer layer of the earth's surface that supports life. It is made up of mineral particles, organic matter, water, and air.

Functions of Soil

Soil acts in the following ways:

- **Medium.** Soil is a medium in which plant roots grow.
- **Anchor.** Soil anchors plant roots so the plant can withstand winds, water, heat, cold, and other forces that might tear it down.
- **Plant food.** Soil is a storehouse of plant food. It must supply nutrients essential for normal plant growth: nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur. It also has certain trace elements, such as iron, manganese, molybdenum, copper, zinc, and chlorine.
- **Water reservoir.** Healthy soil acts as a reservoir of water for a thirsty plant. Each soil has a specific water-holding capacity. A well-developed soil has a honeycomb of connected pore spaces or crevices that act as conduits for much rainwater to enter and pass through the soil to greater depth. The pore space and the external surface of the millions of small soil particles retain considerable useable water called available moisture. This same honeycomb of connected pore spaces provides room for plant roots to grow, keeps air around the roots so they have oxygen for their metabolic

activities, and allows carbon dioxide from root respiration to escape to the soil surface and surrounding atmosphere.

- **Purger.** A healthy soil provides a home for millions of different types of microbes. Just as some of the microbes in the human digestive tract perform activities, some of these microbes do the same, which is essential. Largely due to microbial activity, the topsoil is an intensive transformer of all the waste it collects. The cells and exudates from microbes cause the tiny soil particles to stick together to form more stable soil aggregate. Stable soil aggregates lead to good structure. As a result, more of the rain enters the soil body, less runoff occurs, and soil erosion is reduced. Fueled by the “heat” from decay of plant residues, the enhanced activity of the microbes purges the soil of unwanted organic compounds.
- **Animal home.** The soil also contains many small animals, such as earthworms, termites, and insects. Some of these are helpful and some are harmful.

Soil Profile

Soil profiles are vertical cross-sections of soils in depth. You can see a soil profile on a steep exposed roadside bank or the side of a deep drainage ditch. You will see various layers of soil or rock, one on top of the other. Soils have the following layers:

Topsoil

The uppermost layer of soil, the topsoil is usually from 4 to 15 inches (10–40 centimeters) in depth. It is darker in color and more crumbly than the subsoil just beneath it. This crucial top layer contains most of the organic matter from vegetation. It has most of the plant nutrients, partly because organic matter is a much richer storehouse of nutrients than mineral particles alone. In addition, the organic matter helps create the type of soil structure in the topsoil necessary for growing plant roots. Most of the roots of food crops grow in the topsoil.

Unfortunately, (sometimes disastrously) the topsoil erodes more easily than the next layer of soil. It is especially vulnerable because of its location at the top where it is readily exposed to damage from rainfall splash and wind. The topsoil is the farmer’s life insurance and wealth. It should be judiciously protected!

Subsoil

The layer immediately below the topsoil is the subsoil. Subsoil usually has more clay than topsoil. Ideally, the subsoil holds considerable soil moisture and plant nutrients, although not nearly as much as the topsoil. It is usually more compact and contains less organic matter, which makes it less dark than the topsoil.

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Soils vary greatly in their depth of topsoil and subsoil. The depths of the soil layers and their properties can significantly vary in different parts of the same fields.

Some subsoil is relatively rich in plant nutrients and some is very poor. Some hold much available moisture; some do not. Some are very acidic, so much so that it restricts growth of many crops.

The Dangers of Thin Topsoil

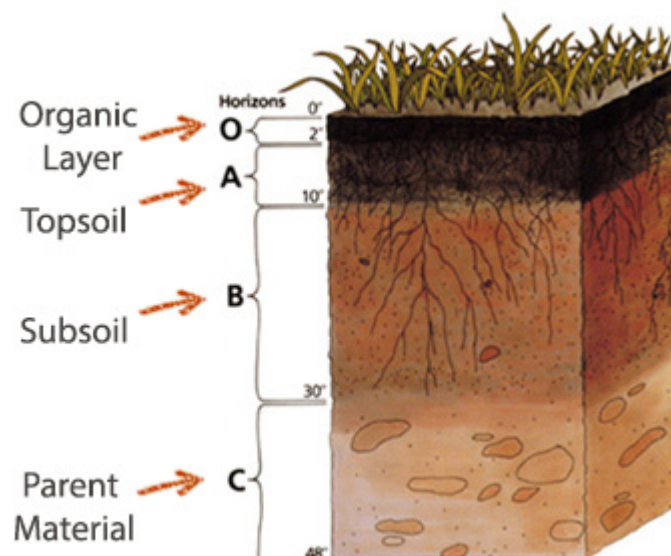
There was a land resettlement project in humid tropical Asia where several thousand families moved to homestead the land. No one had realized that the topsoil would erode very quickly, or that the subsoil was very acidic. The very thin topsoil soon washed away, leaving very acidic subsoil. The acidity was so strong that most food crops could not grow. Since no one could obtain limestone to neutralize that soil, the entire project failed within 5–6 years. There were many abandoned villages. Thousands of resettled people moved away. Such land should have remained as forest in the first place.

As you learn more about soils, keep the subsoil in mind as (1) the future source of topsoil; (2) the moisture reserve storage; and (3) hopefully the nutrient reserve storage. Subsoil, which allows roots to grow deep, adds much to the farm's potential productivity.

Parent Material

Below the subsoil, you may find crumbling or hard rock—sandstone, limestone, or other material—that is the soil parent material from which the soil has weathered. It remains potential additional soil for the distant future.

Figure 1-1. Soil Profile



Soil Composition

A healthy soil has good structure, which has particles of mineral and organic matter interlaced with pore space for air and water, and room for roots to grow. Small channels or passageways allow for passage of air and water from top to bottom.

Figure 1-2. Composition of Healthy Soil

Photo c/o creativecommons.org



The volume of a very good topsoil will usually consist of about 50 percent air, water, and space; 45 percent mineral matter; and 5 percent organic matter. (A peat soil or other organic soil, however, can be composed of as much as 30–50 percent organic matter). Poor management practices that leave the soil exposed to erosion by wind or water will eventually result in a loss of soil fertility.

Time Needed for Topsoil Formation

The conditions that help form topsoil vary widely; therefore, the formation time varies greatly. Under natural (i.e., undisturbed) conditions in a temperate climate, 1 inch (25 millimeters) of topsoil takes from 700 to 7,000 years to form.

When people break up and aerate the soil, and manage it in an excellent manner (using plenty of manures, crop residues, compost, green manure, and commercial fertilizers, and preventing loss of any soil by erosion), less than 100 years may be required.

However, when people break up the soil and do not protect and replenish it, soil loss takes place. Today, such destructive practices are producing seriously degraded land in alarming quantities throughout the world.

Conditions differ in the tropics and, depending on rainfall and temperature, the net length of time for soil formation may be considerably shorter than for the temperate region.

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Factors Affecting Soil Formation

Soils vary greatly from place to place: hundreds of sub-types of soils have formed due to the many variables involved in their formation. Soil formation is a dynamic and ongoing process. At any one site, layers develop in the soil profile because of the following agents:

Weathering

Soils are formed in place by a weathering process from parent materials such as limestone, coral, sandstone, basalt, etc. Depending on their location, rocks are differentially exposed to physical and chemical forces, which cause them to weather differently.

Such rock-mineral weathering of parent material results from its physical disintegration into smaller particles like gravel, sand, and silt; and its chemical decomposition to release compounds. Some elements are very soluble and chemically active. Others stay in place in different forms, or recombine. For instance, the element sodium is very soluble. It leaches (washes) out of the profile, goes to the sea, and accumulates there. Clay (also chemically very active) is a secondary residual mineral that is found in the topsoil and subsoil and stays there. Limestone is a recombination mineral that has stayed in place—in fact, it is still a parent material.

These physical and chemical processes, termed weathering, proceed at different rates depending on the nature of the rock-mineral and the intensity of the forces of weathering.

The higher the temperature and the rainfall, the more rapid and complete the weathering process. (You will find the most weathered soils near the equator.) At higher temperatures, chemical and biological processes accelerate. The speed of chemical reactions doubles for every 212 degrees Fahrenheit (100 degrees Celsius) rise in temperature. The more rainfall, the more leaching occurs and the more weathered the soil becomes. Leaching washes deeper into the soil profile many nutrients not held by the soil. This all means that a soil from the same parent material and of the same chronological age is more weathered (i.e., more “mature”) if located in the high rainfall tropics than, say, in Europe.

Deposition of Vegetation and Animal Life

In addition to forming from minerals as parent materials, soils form from deposits of vegetation and animal life laid down through the centuries. The amount varies. Some soils, such as peat, contain a very high proportion of organic material from vegetation.

Deposition of Soils by Water or Wind

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Certain soils have formed from the deposits of particles moved by streams, seas, or by wind. This gives rise to a mixture of minerals from different parent materials that have been moved from their original sites.

Characteristics of the Parent Materials

Soils form from many types of rocks with different mineral content. Most of the soils of the world are underlain with limestone, shale, and/or sandstone from which they were derived. In some of the mountainous regions of the world, soils have formed from old lava (basalt). Some soils on ocean islands also are of volcanic origin. Others have been formed from coral deposits.

The nature of the parent rock strongly affects the mineral content and acidity of the soil. Some rocks like sandstone and granite, for example, make more acid soils than limestone or volcanic basalt do.

Alluvial soils are soils that have been transported by water and deposited elsewhere. Such soils, usually composed of topsoil accumulated in layers of various depths, are usually very fertile. There are deep, rich alluvial soils in many river valleys and deltas—for example, the Mississippi Delta in the United States, the Nile Delta in Egypt, and the Ganges Delta in India. Rich soils still yield profusely along the Nile and the Ganges rivers after at least 5,000 years of crop production, primarily because the soils are rejuvenated through periodic flooding, leaving rich topsoil deposits.

Loess soils are formed from soil particles blown to new locations by the wind and deposited to varying depth. Loess soils are often silty, sometimes fairly fertile, but highly erodible. Many soils along the Missouri-Mississippi River Bluffs originated in this manner.

The many climates in the world—the variations in temperature, rainfall, wind, and humidity—make or unmake the many kinds of soil. Rainfall and temperature, especially, affect soil formation.

Climate Effects on Vegetation

Temperature and rainfall also determine what vegetation, and how much of it, will grow. This, in turn, affects the amount and type of organic matter in the soil and the soil fertility.

For example, tree growth is favored in humid regions where rainfall exceeds evaporation. Where evaporation exceeds rainfall, grasslands are the dominant vegetation. Forests, thus, grow on soils where most of the soluble nutrient elements have been leached from the root zone or carried by water to the sea. In grasslands, enough rain falls to dissolve some of the

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minerals; but not enough has fallen to leach the nutrient elements from the soil profile. Forest soils are, hence, acid, while grasslands are neutral or alkaline.

Length of Time

Soils vary in age tremendously. For example, a river valley might have thousands of hectares with young, very recently deposited alluvial loamy topsoil only 500 years old and several meters deep. Underneath this might be long-weathered soil several thousand years old. The nearby hillside soils might also have been weathered for thousands of years.

Topography

Local and regional topography strongly influences soil formation.

The elevation and slope of the land affects the temperature. High elevation or exposure to shade from high mountains will lower temperatures, which will lower the rate of soil weathering and the amount of vegetation produced for organic matter.

The microclimate on one side of the mountain or steep hill can be quite different from that on the other. The amount and intensity of sunshine, rainfall, and the prevailing winds can be very different on opposite sides of mountains. One side may have plentiful rainfall, and the other side may suffer from drought.

In the tropics on high hilly land near the ocean, the ocean side may experience intense frequent rains, while the inland side may receive very little rainfall.

Soil formation on the sunny, warmer south slope of a hill is faster and more complete than on the north side of the same hill. Some minimal erosion on a hillside occurs over the years under natural conditions. However, if vegetation covers the hillsides, good soils form and accumulate.

Because of the slope, hillside soils are usually well drained. Poor drainage may exist in depressions and pockets in the lowlands, resulting in limitation of plant growth due to inadequate air space in the pores of the soil. In the tropics, the well-drained soils (yellow, orange, and red) are usually found on slopes of rolling land, as well as the gray and some black soils in poorly drained areas.

Different Types of Trees, Shrubs, and Grasses

The soil reflects the kind of vegetation that has grown on it over the years. In the natural environment, much of the vegetation returns to the earth and decomposes to become part of the organic matter in the topsoil.

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Soils formed under grassland and less rainfall will differ from soils formed under forests and higher rainfall. Even within forests, different varieties of trees may help produce different soils.

Forest soils have accumulations of leaves and litter on their surface. Microbial decay produces strong acids, which dissolve nutrient elements from the minerals more completely, leaving silicate clays and oxides of iron and aluminum.

Grasslands accumulate residues at considerable depth. This is due to the penetration of their fibrous root systems (which go deep, spread out, and later decompose), in addition to the organic matter from the top. Still, the acids released by microbial growth enhance the breakdown of nutrient-containing minerals.

Land and Crop Management by the Farmer

The present soil fertility, soil structure, and topsoil depth of a particular farmer's field depend largely on the answers to questions such as:

- Is the topsoil eroded or still intact?
- What farming practices does the farmer use? What practices have the farmer's ancestors followed? Have they terraced the land or farmed it on the contour?
- Have they rotated the crops? What kinds of crops have they grown and what fertilizers, if any, did they use?
- Especially, have they used legumes in their crop rotation?

In many societies, women and men have different roles and responsibilities. Just as they have different household responsibilities, they also have different responsibilities in relation to food production. This means that women and men very often have varying effects on the surrounding landscape and varying abilities to make changes to established practices. Women are often responsible for the bulk of subsistence production, so it makes sense for Volunteers to work with them to improve the productive capacity of the agrifood system. However, in many cases it will be necessary to work with both women and men, even if certain practices are gender-specific, because changes to land and crop management are social and cultural, and therefore affect everyone in the community. In addition, it is important for Volunteers to be aware that women and men experience different opportunities and constraints. For example, even women within one household will be affected by varying constraints and opportunities due to differences in, for example, age, location, ethnicity, and status within the household.

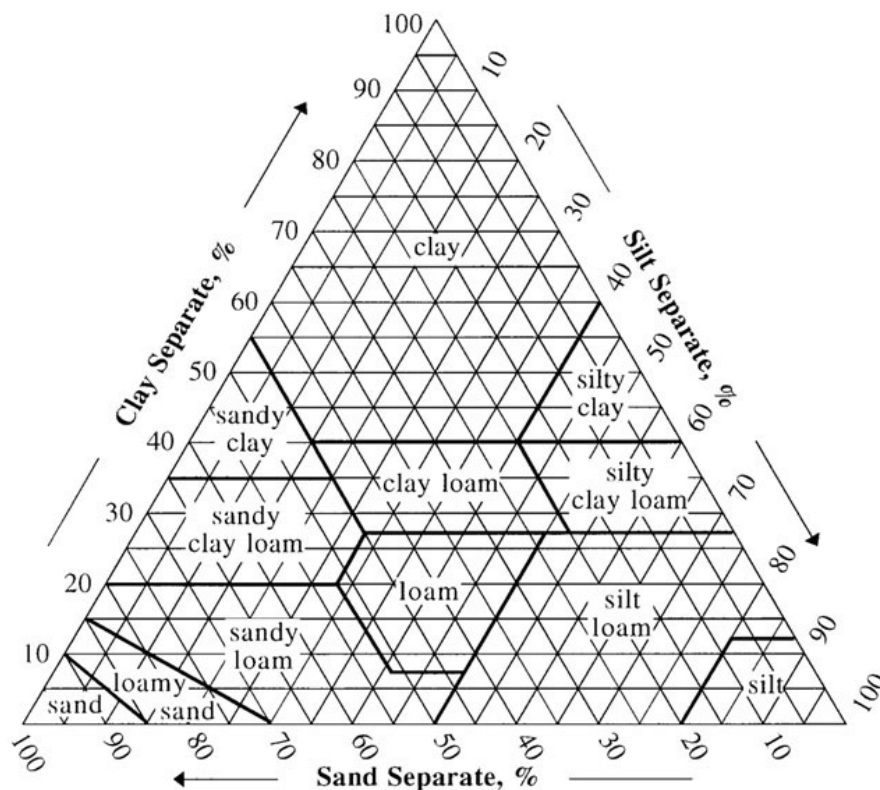
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Soil Texture

If you have ever collected sand in your shoes at the beach, and almost lost your shoes when they got stuck in muddy clay, you already know how soils vary in texture. The term “soil texture” describes the relative proportion of sand silt and clay particles in a soil.

Although the soil contains organic matter, air, and water, scientists do not consider these when classifying soils according to texture. They consider only proportions of the sand, silt, and clay particles in any given soil. Classifications are typically named for the primary constituent particle size or a combination of the most abundant particle sizes (e.g., “sandy clay” or “silty clay.”) A fourth term, loam, is used to describe a roughly equal concentration of sand, silt, and clay, and lends to the naming of even more classifications, e.g. “clay loam” or “silt loam.” In the United States, the U.S. Department of Agriculture (USDA) defines 12 major soil texture classifications. Determining the soil textures is often aided by the use of a soil texture triangle.

Figure 1-3. Soil Texture Classification Triangle



For example, using the triangle, a loamy soil has 40 percent sand, 20 percent clay, and 40 percent silt. A sandy loam has 60 percent sand, 10 percent clay, and 30 percent silt. Sandy loam soil with 30 percent clay, 50 percent sand, and 20 percent silt is called a sandy clay loam.

Importance of Soil Texture to the Farmer

The texture of the soil greatly affects the soil in many of its relationships to plants and water: how much water it retains; how well water drains from it; how fertile the soil is; how easily the soil can be tilled; what crops can be produced; how large the crop yield is; and how susceptible the soil is to erosion.

Soil texture tends to change with depth. A deeper soil usually has a higher proportion of clay than the topsoil. Note that soil textures can vary in different locations in a single field. Farmers need to be aware of this when they are dealing with soil and crop management.

Size of sand, silt, and clay particles

The mineral particles in the soil vary tremendously in size, from clays (the smallest), to silts, and to sands (the largest and coarsest). Scientists classify soil particles according to size, plus some chemical characteristics.

The following table shows the classification of particle sizes and the names used by most soil scientists in the United States. Sizes are measured by shaking soils through mesh screens, going from small to large. The finer clay particles are determined by the time it takes for them to settle out of the “muddy” water.

Table 1-1. Particle Sizes

Name	Size in Millimeters
Clays	000.0.002 millimeters or less
Silt	0.000.002 to 0.05 millimeters
Very fine sand	0.050.05 to 0.1 millimeters
Fine sand	0.0.1 to 0.25 millimeters
Medium sand	0.25 to 0.5 millimeters
Coarse sand	0.0.5 to 1.0 millimeters
Very coarse sand	1.0 to 2.0 millimeters
Gravel	Above 2.0 millimeters

Characteristics of Sand, Silt, and Clay Particles

Sand

- Sand will feel gritty when you hold moist soil in your hand and squeeze a bit of it. It ranges in size from 0.002 to 0.08 inches (0.05–2.0 millimeters).

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- Mixed particles of sand laid side by side might equal about 125 particles per inch (25.4 millimeters). Very coarse sand particles side by side might only be 25–30 particles to the inch.
- Most sands are quartz (silicon dioxide). They have few plant nutrients and hold very little moisture for plant use.
- Sands in the soil help keep space available for air and water to circulate around plant roots.
- Sands help make the soil more workable when moist. Sands in the soil improve ease of tillage.

Silt

- Most of these very fine particles are also made of quartz. However, they would measure about 500 to more than 5,000 (or many more) particles to the inch if laid side by side.
- Since silt particles are so much smaller than sand, they have more total surface exposed for a given volume. This greater external surface gives them more chemical activity and water-holding capacity than sand. Often, some silt particles are coated with clay and therefore contain more plant nutrients than sand.
- Silts serve as mineral reserves for releasing nutrients to the clay and organic fractions of the soil.

Clays

- Clay particles are very small. If laid side by side, 10,000 to 12,000 clay particles or many more would be required to measure an inch. Therefore, the exposed surface area is very great.
- Clays can hold much more available soil moisture and nutrients than silt or sand.
- Clays are active chemicals. They have negative (-) electrical charges that attract and hold positive (+) electrical charges of plant nutrients, such as potassium, calcium, magnesium, and many others.
- Each type of clay has a certain holding (storage) capacity for positively charged plant nutrients, called cation exchange capacity (CEC). Soils that formed under intensive weathering contain clays with fewer negative charges. This strongly affects their management. In addition to the negative charges, some tropical clays also have a few positively charged sites. These clays are, therefore, also in negative ion fertilizers such as nitrate nitrogen. Because clays hold much of the positive-charged nutrients, and some tropical clays also hold a little negative-charged plant food, they are truly special soil particles. They attract and hold many plant nutrients and keep them from washing (leaching) below the plant root zone.

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- Heavy clay soils are difficult to plot. The moisture content has to be just right. (We have all seen the stickiness of modeling clay and its ability to dry hard.) Most farmers prefer for clay soils to have a certain percent of sand in them making them easier to till.

How to Recognize Soil Texture on the Farm

Often the farmer may only need to recognize his soil as being mostly sand, loam, or clay. However, the tables and graphic on the next two pages will help you identify them more specifically. Take your notes to the field with you and practice determining soil types in various locations.

Table 1-2. Determining Soil Texture in the Field

Soil Type	Visual Appearance	Squeeze test	Feel When Moist*
Sand	Loose, single-grained	When dry and squeezed, it falls apart when released. If wet, it crumbles readily when touched.	Gritty
Sandy Loam	Loose	When dry and squeezed, it falls apart easily when released. If wet, it forms a cast that crumbles without careful handling.	Gritty
Loam	Few clods	When dry and squeezed, it forms a cast that needs careful handling. If wet, the cast can be freely handled without breaking.	A bit gritty but slightly putty-like (plastic)
Silt Loam	Cloddy, but clods are easily broken	Same as above.	Only slightly plastic or gritty; feels like talcum powder
Clay Loam	Cloddy and lumpy when dry	When wet and squeezed, it forms a cast that holds together under heavy handling.	Plastic; forms a ribbon when rubbed between forefinger and thumb but it breaks easily
Clay	Hard lumps or clods when dry	The wet cast can be tossed and caught without breaking.	Very plastic and sticky; forms a ribbon easily

**If dry, add water drop by drop, knead the soil to break down all clumps until soil feels like moist putty. If too wet, add dry soil to soak up the water. (Source: Leonard, D. 1986. Soils, Crops, and Fertilizer Use, 4th ed.)*

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Figure 1-4. How to Determine What Makes up a Soil?



Take a glass jar or bottle and fill it about one-third full of soil from a representative soil sample. Fill the vessel with water. After securing the lid, mix the soil and water thoroughly by continuing to reverse the ends of the jar. Continue doing this for about 5 minutes. Set the sample on a level shelf or table. Do not move it for 24 hours.

The sand will settle to the bottom, the silt will be next, and the clay will be on top.

More About Clays

Clay particles, the “magicians” of the soils, are also the food-plant nutrient banker. They keep plant nutrients in storage until plant roots withdraw them. They are chemically active. Since they are so tiny, their outside surfaces add up to a tremendous total surface per unit volume of soil. One (1) cubic centimeter of clay particles can have at least 1 square meter of total surface to be used for plant nutrient and moisture storage!

Clays are vital because they and organic matter are the chief mechanisms in the soil holding most plant nutrients. They prevent leaching of positively charged plant nutrients. Without clays and organic matter, plant nutrients would wash right through the soil.

Table 1-3. Types of Clays

Name	Description
Entisols	Young, recently deposited soils
Oxisols	Highly weathered
Ultisols	Highly leached
Alfisols	Less weathered and leached

Acidity in Tropical Soils

Some of the soils in the tropics in their natural state are acid. The majority of the cultivated soils, however, are not strongly acid. Early farmers and ranchers chose the better soils free of serious acid problems. Nowadays, population pressures are forcing more and more people to farm marginal lands, some of which may have medium acid to strongly acid soils.

Soil Acidity and the pH Scale

In rating the acidity of a soil, we use a soil acidity scale called the pH scale. In it, pH 7 is neutral, below pH 7 is acid, and above pH 7 is alkaline. The scale is a logarithmic function (not a straight-line relationship if plotted on regular graph paper). In other words, a pH of 4 is 10 times more acid than pH 5 and 100 times more acid than pH 6. A pH 9 is 10 times more alkaline than pH 8 and 100 times more alkaline than pH 7.

More acid soils are usually found in heavier rainfall areas and more alkaline soils are found in arid and semi-arid regions. A large percentage of the soils of the tropics have a pH 6 or below. Tropical Asia and Africa apparently have fewer hectares of acid soils than tropical America. However, keep in mind that Latin America and Asia have developed successful, sustained soil management systems in many regions. One indication of their success is that these countries have sustained increases in per-capita food production in the tropics.

Table 1-4. Soil Acidity Values, the pH of Soils

pH Value	Degree
8.2–8.6	Strongly Alkaline
7.5–8.2	Medium Alkaline
7.0–7.5	Slightly Alkaline
7.0	Neutral
7.0–6.4	Slightly Acid
6.4–5.8	Moderately Acid
5.8–5.2	Medium Acid
5.2–4.7	Strongly Acid
4.7–3.8	Very Strongly Acid

Source: Sprague, H.B. 1982.

Plant Growth Problems of Acid Soils

Some major plant growth problems associated with very strongly acid, strongly acid, and certain medium acid soils are aluminum toxicity, manganese toxicity, calcium deficiency, and

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magnesium deficiency. Any one of the four can limit plant growth. The following outlines how to deal with toxicities and deficiencies of tropical acid soils.

Aluminum Toxicity

Aluminum toxicity decreases plant growth and actually harms the plant roots. The very acidic soils of the tropics often have high aluminum levels, which are toxic to some food crop plants. Aluminum toxicity is often the major problem in low pH soils.

The farmer can correct this by adding enough finely ground limestone to the topsoil of the field to bring the soil acidity up to pH 5.5–6.0 in the top 15 centimeters of soil. Another alternative is to grow native plants, which tolerate these acid conditions.

Manganese Toxicity

Manganese toxicity can occur in acid soils high in soluble manganese. Adding enough limestone to the soil to adjust the topsoil acidity to pH 5.5–6.0 in the top 15 centimeters of soil will take care of the toxicity.

Calcium and Magnesium Deficiency

To correct calcium deficiency in soils, the farmer can add finely ground limestone as a calcium fertilizer. Applying this as a general application to adjust the pH of the whole field may be impractical. The farmer can, instead, place the limestone along the side of the plant row, 10 centimeters to the side and buried 10 centimeters deep. This method of fertilizer application is called “side dressing.” Side dressing with a fertilizer like dolomite limestone, which contains both magnesium and calcium, will correct magnesium deficiency in a soil, as well as calcium deficiency.

Acid-tolerant Crops

Finding crops that can handle high acidity is one partial solution to problems of acid soil. Certain crops (or even a different variety of a susceptible crop) can tolerate such soil. Many plants already growing in the tropics do much better with problems of soil acidity than crops such as soybeans, which have been introduced from other regions.

Some crops that adapt well to many local acid soil conditions are pineapple, coffee, tea, cassava, cowpeas, black beans, sweet potatoes, some sorghums, some varieties of rice, and watermelon. Other plants with acid tolerance are Guinea grass (*Panicum maximum*), Jaragua (*Hyparrhanea rufa*), molasses grass (*Melinutiflora*), tropical kudzu (*Pueraria phaseoloides*), *Stylosanthes humilis*, and *Desmodium intortum*.

Many of the food crops above do not form a completely balanced diet, especially of complete protein. However, certain combinations do (such as black beans plus unpolished rice). If forced to use acid land, the farmer may have to attempt to grow what will grow, and supplement the diet from other sources, possibly small animals such as rabbits, guinea pigs, and poultry.

Soil Organic Matter

Importance of Soil Organic Matter to the Tropical Smallholder Farmer

Soil organic matter originates from plant materials and some animal materials. Their breakdown performs vital functions in plant growth. The soil depends on organic matter, often laid down naturally in surface litter, for continual replenishment and to rebuild the fertility and productivity of the soil. Keeping organic matter content high is an important consideration in sustaining the soil. Yet, the organic matter may be hard to come by, as it often serves as fodder for animals. In addition, the application of organic matter may be considered overly laborious by the farmer. A task for Volunteers is to assess whether there are viable ways to improve opportunities for increasing the application of organic matter.

The urgency of maintaining a high level of organic matter content in the farmer's soil cannot be stressed enough, because:

- High levels of organic matter increase plant nutrients in the soil and increase crop yields.
- Organic matter greatly increases the water holding capacity of sandy soil. More water is kept available for plants to use. More plant growth results.
- High levels of organic matter supply most of the cation exchange capacity for topsoil of highly weathered tropical clays and for sandy soil. That is, their negative charges hold the positive-charged plant nutrients.
- Organic matter also furnishes most of the nitrogen, sulfur, and much of the phosphorus (which are not positively charged) where commercial fertilizers are not used.
- Organic matter interacts with clays in a number of ways to improve old, highly weathered tropical clay soils.
- Organic matter improves the soil structure increasing space for plant root growth and allowing better aeration. It improves the tilt of the soil. (Tilt refers to the ease with which a soil can be cultivated. If the soil is crumbly, the plant roots penetrate it easily.)
- In some soils, organic matter keeps much phosphate from being tied up ("fixed"), i.e., it keeps phosphate available for plants to use. It also helps keep many micronutrients available for crop roots to absorb.

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- In some soils, organic matter with its slower release schedule prevents leaching of nutrients. It differs from commercial nitrogen fertilizer that is released all at once when it receives the first rain. (Much leaching can occur with commercial nitrogen. Therefore, the farmer should apply split applications—two or more applications instead of one—of commercial fertilizer according to the plant's expected growth rate and need.)
- In most soils, by improving structure, organic matter increases the infiltration rate (the rate at which water enters the soil). This conserves rainwater and reduces the amount of runoff water during rainstorms, which reduces soil erosion.

Formation of Soil Organic Matter

When more plant residues (tree leaves, crop litter, etc.) are left to accumulate on the topsoil or be worked into it, more organic matter occurs (until it reaches equilibrium with temperature and moisture). However, this is also determined by the rate of decomposition. Rapid decomposition will use up organic matter faster.

Deposits of Plant Residues

Forests tend to deposit more litter than crops do. Therefore, when farmers clear forest land and put in crops, the land receives much less plant material back into its topsoil. If the quality of topsoil is to remain constant or to improve, farmers must add extra amounts of organic matter in addition to the food crop residue (see succeeding chapters on compost, green manure crops, alley cropping, etc.).

Decomposition of Plant Residues

Various microorganisms decompose plant or animal residues on or in the soil, breaking them down to organic matter, which becomes an integral part of the topsoil.

Replacing forests with crops reduces the amount of plant residue returned to the soil. Additionally, cultivating the land mixes more air and more oxygen into the soil, which more than doubles the rate of organic matter decomposition and the breakdown of plant materials.

Rates of decomposition are faster in warm, wet tropical regions than in dry, cool ones. The organic matter breaks down and burns up faster. Under the wet-dry season conditions of much of the tropics, organic decomposition slows down during the dry season, much as it slows in cold winter months in a temperate climate. In the tropical areas with wet-dry season patterns, organic material decomposes about one-fourth to one-half as fast as it does in tropical moist areas with no dry season. The actual rate of reduction depends on the length of the dry season.

Humus

Humus is the temporary product of organic matter decomposition produced by microbial action in the soil. There is more life below the surface of a soil than there is above it! One tablespoonful of soil contains billions of microbes. Many different kinds exist, each doubling every 20 minutes when its preferred food (plant residue) is supplied. Most microbes like proteins and sugars, while others get energy from celluloses. Few digest fats, waxes, and lignin. These, along with dead microbial cell materials, become humus.

Humus has almost miraculous powers in the soil. As organic matter decomposes, it releases various plant nutrients into the soil and the soil solution for plant consumption, including nitrogen and phosphorus. Humus packs powerful negative charges—more than 20 times as much as some of the old weathered tropical clay. It can therefore store much larger amounts of positive charged plant nutrients, such as calcium, potassium, magnesium, and others, as well as certain trace elements (iron, zinc, etc.). It reacts with both clays and cations.

Comparing Organic Levels of Soils in the Tropics and in Temperate Zones

Under natural forest conditions, the percent of organic matter in the top 20–30 centimeters of soil is about the same in the tropics and in moderate climate soils—from 1 to 5 percent. Under continuous rainfall and warmer temperatures, more plant growth takes place and is left on the ground in tropical forests. However, it also decomposes much faster in the tropics. The net results are that organic levels in natural forest soils may tend to be comparable for many moderate and tropical conditions.

How to Obtain and Keep High Levels of Organic Matter in the Field

- Do not burn the fields to clear them for planting. In many parts of the world, farmers burn the grass and stalks that remain after harvest. Sometimes thick smoke haze extends for miles. Burning weeds and post-harvest trash saves labor, but valuable organic material goes up in smoke!
- Leave post-harvest trash, stems, leaves, etc., on the ground. This residue acts as partial mulch, helps fight “raindrop splash” erosion, and eventually becomes more soil organic matter.
- Use as few tillage operations as possible. Avoid breaking up the soil or its cover. Begin to think about conservation tillage (discussed in Chapter 3). A single, very heavy rainstorm can wash away much of the organic matter from a bare, cultivated steep slope. Tilling the soil also increases the rate of oxidation (the rate of metabolism and the rate of burning up organic matter).
- Keep a cover on the soil in every way possible. Protect the soil from “raindrop splash erosion” (more about this in the next chapter).

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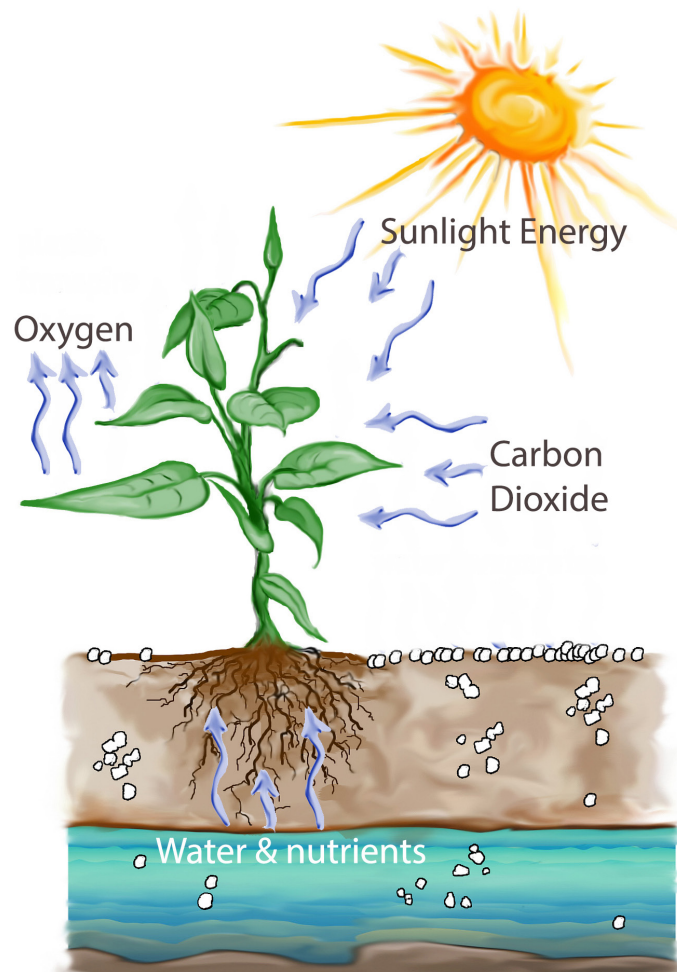
- Protect the soil from excessive heat. A hot, bare, moist soil burns up organic matter quickly. The sunshine raises soil temperatures excessively and increases microorganism activity at a very high rate. A lot more organic matter burns up.
- Mulch the soil. Mulch shades the soil, usually feeds it (depending on the material in the mulch), and helps protect it from erosion.
- Keep the soil covered with vegetation (see Chapter 3.)

Soil, Water, and Plant Relationships

Crops and soils work together with air (carbon dioxide), sunlight, and water in a unique kind of “factory.” The soils provide nutrients and water to the plants; sunlight supplies the energy; and the air supplies the carbon dioxide. The plants use these “raw materials” to manufacture products (the crops). The crops then give back the benefits of organic matter to the soil.

Figure 1-5. Plant Relationships

Photo c/o creativecommons.org



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The effective functioning of this unique interacting system depends on a number of factors. For photosynthesis and other processes, plants must have sunlight; carbon dioxide from the air; water and air in the soil for the roots; appropriate temperatures for growth; and 16 essential plant nutrients in sufficient amounts. Plants require some of the elements in only minute trace amounts. However, all of them must be present in the amount needed. If not, the plant does not grow normally, or may not grow at all.

Table 1-5. Chemical Elements Necessary for Plant Growth

Name	Symbol
Macronutrients	
Carbon	C
Hydrogen	H
Oxygen	O
Nitrogen	N
Phosphorus	P
Potassium	K
Calcium	Ca
Magnesium	Mg
Sulfur	S
Micronutrients	
Iron	Fe
Boron	B
Copper	Cu
Manganese	Mn
Zinc	Zn
Molybdenum	Mo
Chlorine	Cl

Plants require the first nine elements, the macronutrients, in relatively large amounts. They require the micronutrients, or trace elements, in minute trace amounts. Air and water supply carbon, hydrogen, and oxygen to the plants. The rest of the elements come from the soil.

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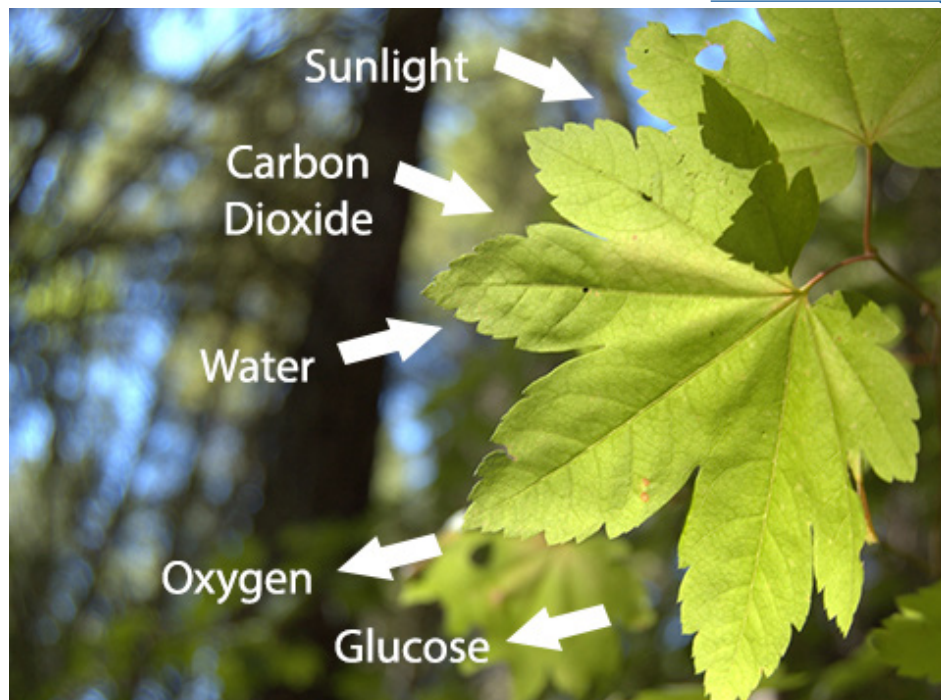
Plant Processes Important to Plant Life and Growth

Photosynthesis

Photosynthesis uses the chlorophyll in the green leaves of plants, sunlight, carbon dioxide, and water to produce sugar. From sugars, the plant makes the carbohydrates, proteins, and many complex products needed for plant life, reproduction, and growth.

Figure 1-6. Photosynthesis

Photo c/o creativecommons.org



Transport

At the same time, plant roots take up the needed nutrients and moisture from the soil and the plant system sends, from the leaves back to the roots, sugars and other chemical products needed for energy and growth. In order for normal growth to occur, the nutrients and moisture from the roots, as well as the products from photosynthesis, must be available to all parts of the plant at the same time.

Two systems within the plant transport the materials for plant processes. One carries water and chemical nutrients from the root zone to all parts of the plant. Simultaneously, the other conveys the products of photosynthesis to the growing points throughout the roots and the plant system. For the transport system to work well, the plants must get enough moisture at all times to keep the plant cells turgid.

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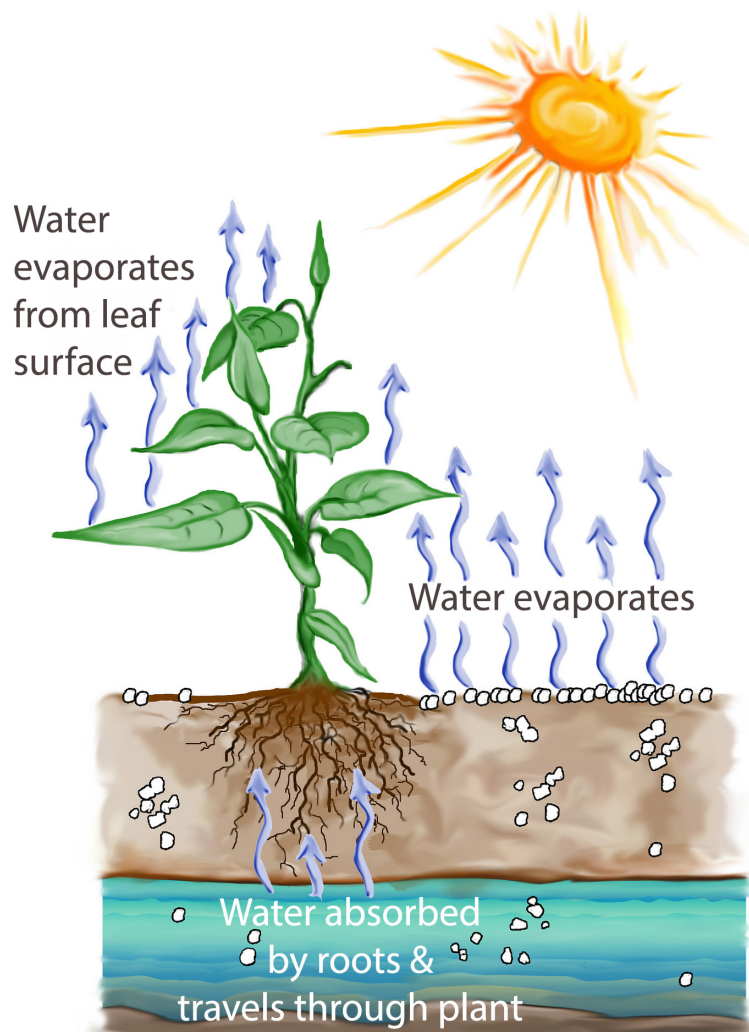
Transpiration

Transpiration from the leaves affects the plant. The surface of plant leaves has openings or pores that allow gases to pass back and forth between the air and the plant tissue. The openings, called “stomata,” allow water vapor to leave the plant and air to enter. Highly sensitive guard cells control the opening and closing of the stomata. They open the stomata in daylight hours and close them at night. Even in the sunlight, the guard cells will close or partially close the stomata when the plant is under moisture stress, thus protecting the plant cells from excessive desiccation.

The water lost from the plant is said to have been “transpired.” The combination of water loss through evaporation from the soil surface and water loss through the plant is called “evapotranspiration.”

Figure 1-7. Transpiration

Photo c/o creativecommons.org



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Effect of Air, Light, and Temperature Factors on Plant Growth

Ambient Temperature

The day and night ambient temperature (temperature of the air in the shade) affects not only the growth of different species of plants, but also which ones can grow. The requirements for different species of crops vary widely.

Crops such as cabbage are cool season crops. In the United States, cabbage grows best in the spring and the fall. In the tropics (where four yearly seasons are lacking), it does best in the mountains where days are warm and nights are cool. Fruit trees usually do better with cool nights. Some other crops can do well with warm days and nights. Some plants are cold weather hardy while others are not.

Soil Temperature

The best soil temperature for plant growth varies widely from species to species. However, most plants fall into the range of 68–86 degrees Fahrenheit (20–30 degrees Celsius).

The soil temperature affects plant roots. Plant roots of different species have specific ranges of temperature in which they grow well. In the tropics, most roots of food crops in the topsoil grow better in a cool moist soil under mulch than in a very hot soil fully exposed to the direct tropical sunshine.

Soil temperature also affects microorganisms living in the soil. As the soil temperature increases from about 41 to 86 F (5–30 C), the rate at which microorganisms decompose organic matter increases. In the above range, the rate of microorganism activity will increase two or three times for each rise of 50 F (10 C) in soil temperature.

Direct sunshine on bare soil greatly increases the soil temperature for a depth of several centimeters. If the soil surface is shaded or covered with mulch and kept cooler, root growth will increase and the decomposition of organic matter will be diminished. It, thus, remains useful to the soil longer.

Light

Different plant species vary greatly in their requirements for light. Some plants require full sunlight to maximize their photosynthetic processes. Some do well in partial shade, while some others can even thrive in full shade. Knowing the light requirements of various species becomes highly important when growing plants together, side-by-side, or some beneath shade in a farmer's field.

Light affects plants in other ways. The length of daylight (day length) or the length of night controls the ability of some plants to produce flowers and fruit. Some species do well with either a short or long day. Check with local volunteer specialists before introducing plants from outside the region.

Humidity

Hot, dry air increases the plant's loss of water (transpiration rate). The plant will use much less water when there is high humidity. Although high humidity decreases plant transpiration rates, it can have a negative influence on plants by creating an ideal environment for certain plant diseases to grow.

Effect of Soil Moisture on Plant Growth

Field Capacity

As a quantity of rainfall water or irrigation water moves down through the soil pore spaces, it saturates the entire soil mass. After the rain stops, or irrigation is finished, the soil water continues to drain, pulled by the force of gravity. Usually most of the drainage stops after 24 hours. The soil moisture is then at "field capacity" (the amount of soil moisture a given soil will hold against the pull of gravity). Most of this remaining moisture can be used for plant growth.

The amount of moisture in a soil at field capacity should not change significantly for several weeks, assuming no plants are growing, heavy mulch is not on top of the soil, and no additional water is added.

Available Soil Moisture

Suppose that seeds are planted into a soil at field capacity, through mulch, with minimum disturbance of the soil. The mulch on the surface keeps wind and sunshine from evaporating the soil moisture. Under these controlled conditions the amount of water available for use by the crop depends on two things: the water-holding capacity of the soil and the rooting depth of the soil and plants.

We call most of this the available soil moisture. It is the amount of water a plant can extract from a soil before it becomes extremely wilted.

The permanent wilting point is the point at which the soil moisture remaining in the soil is held so tightly by adsorption by the soil particles that the plant can no longer extract water and becomes severely wilted. Unless the plant receives water, it will soon die.

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Available soil moisture is the difference in the soil moisture content at field capacity and the amount of moisture at the permanent wilting point. Available soil moisture for plant use is expressed in inches of water available per foot of soil depth, or centimeters of water per meter of soil depth. Notice the large difference between sands and loams, or sands and clay soils, in the following table.

Table 1-6. Available Water-holding Capacity of Soils

Soil Type	Inches of Available Soil Moisture for Plant Use	Inches per Foot
Sands	0.25 - 0.75	21-63
Fine loamy sands	1.40 - 1.70	117- 142
Clay loams	1.75 - 2.50	146- 208
Clays	2.00 - 2.60	167-217

Variables Affecting Plants' Moisture Needs

Water Use Rate

The water use rate varies with the amount of sunshine and wind, the water content of the air (humidity), the stage of plant growth, and the amount of moisture evaporated from the soil surface.

Bareness

When the soil is bare, a large amount of water evaporates from the soil surface due to sunshine and wind. As we all know, hot sunshine dries out bare soil quickly, even more quickly if a dry wind is blowing. However, a mulch cover over the soil can prevent much of the water loss, except for loss from transpiration through the plant leaves.

Leaf Surface

Low-growing crops will usually use less water than a tall crop like corn, which has many leaves rising into the air. More leaf surface means more transpiration.

Stages of Development

Crops use more water during the stages of pollination, seed formation, and maturation of fruits, seedpods, or ears. At this time, the nutrient and moisture needs of plants are at their peak.

Table 1-7. Average Daily Water Requirements for Field Crops

Daily Water Requirements for Field Crops	
Very young plants	3 or 4 millimeters/day
Fast-growing field crops at peak use (when grains are filling, maturing)	6 to 10 millimeters/day or more

**Assumes good growing weather and full sunshine*

Importance of Good Soil Fertility

Good soil fertility is one of the first steppingstones for successful small farm development. A highly fertile soil not only produces excellent yields, but also enhances soil and water conservation.

Good soils produce abundant crops with healthy root growth. This, in turn, helps keep the soil in good condition and potential organic matter is available. The higher the yields and the more lush the plant growth, the greater the amount of organic matter that can be left in the field after harvest time.

Deficient Nutrients in Tropical Soils

Many soils in the tropics will have adequate supplies of all the required nutrients, except nitrogen, phosphorus, potassium, and calcium.

If you look at commercial fertilizer bags in developed countries, you will see N–P–K written across the middle of the bag. Figures written under each letter give the percent of each element contained in the bag. For example, 10–10–10 under the letters N–P–K means that the material contains 10 percent nitrogen fertilizer, 10 percent phosphorus fertilizer, and 10 percent potassium fertilizer. In some developing countries this may not be the practice.

Fertilizer needs depend on what nutrients different types of crops extract from the soil each year and what nutrients they need at different yield levels. The following table gives you an idea of fertilizer nutrients extracted by different crops at different production levels.

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Table 1-8. Nutrient Removal by Major Tropical Crops

Crop	Part	Yield* (tons per hectare)	N	P	K	Ca	Mg
Cereals							
Corn	Grain	1.0	25	6	15	3.0	2.0
	Stover**	1.5	15	3	18	4.5	3.0
	Total	2.5	40	9	33	7.5	5.0
	Grain	4.0	63	12	30	8.0	6.0
	Stover**	4.0	37	6	38	10.0	8.0
	Total	8.0	100	18	68	18.0	14.0
Rice	Grain	1.5	35	7	10	1.4	0.3
	Straw	1.5	7	1	18	2.6	2.2
	Total	3.0	42	8	28	4.0	2.5
	Grain	8.0	106	32	20	4.0	1.0
	Straw	8.0	35	5	70	24.0	13.0
	Total	16.0	141	37	90	28.0	14.0
Sorghum	Grain	1.0	20	0.9	4	4.0	2.4
	Straw	1.2	6	0.4	2	4.6	3.2
	Total	2.2	26	1.3	6	8.6	5.6
	Grain	8.0	35	10.0	27	16.0	9.6
	Straw	8.0	35	4	13	18.0	12.8
	Total	16.0	170	14.0	40	34.0	22.4
Finger Millet	Grain	1.1	17	5	59		
Root Crops							
Cassava	Roots	8.0	30	10	50	20	10
	Roots	16.0	64	21	100	41	21
	Roots	30.0	120	40	187	77	40
	Whole Plant	59	64	19	176	102	26
Potatoes	Roots	12.0	52	10	80	22	14
	Roots	22	120	20	166	40	26
	Roots	40.0	172	34	232	70	48
	Whole Plant	62.0	147	19	403	60	31
Sweet potatoes	Tubers	44.0	77	14	224	4	9
	Roots	16.5	72	8	88		

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Crop	Part	Yield* (tons per hectare)	N	P	K	Ca	Mg
Grain Legumes							
Beans	Dry Beans	1.0	31	3.5	6.6		
Soybeans	Beans	1.0	49	7.2	2.1		
	Peanuts	1.0	49	5.2	27		
Grasses							
Guinea	Above ground	10.0	107	27	180	78	49
	Above ground	23.0	288	44	363	149	99
Elephant	Above ground	10.0	144	24	180	35	30
	Above ground	25	302	64	504	96	63
Other Crops							
Sugar cane (2-year crop)	Above ground	100	75	20	125	28	10
	Above ground	200	149	29	316	55	58
Cotton (Seeds)	0.8	30	4.4	7			
Coffee		Dry beans	1.0	25	1.7	16	1
Tea	Dry leaf	0.6	31	2.3	15	2	
Tobacco	Cured Leaf	1.0	116	14	202		
Rubber	Dry latex	3.0	7	1.2	4	4	
Cacao	Dry beans	0.5	10.	2.2	5	1	1
Oil Palm	Fruit	15.0	90	8.8	112	28	
Bananas	Bunch	10.0	19	2.0	54	23	30
	Stem and leaves	--	20	1.3	22	1	3
	Total	10	39	3.3	76	24	33
	Bunch	30.0	56	6.0	161	70	82
	Stem and leaves	--	29	4.0	65	2	8
	Total	30	39	85	10.0	72	90

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Crop	Part	Yield* (tons per hectare)	N	P	K	Ca	Mg
Pineapples (Fruits)	Fruits	12.5	9	2.3	29	3	
Coconuts	Dry copra	1.2	60	7.2	40		

*Yields of cereals, grain legumes, and grasses on a dry weight basis; root crops and bananas at 15–20 percent dry matter

**Stover = stalks and leaves of crops like corn, excluding leaves.

(Used with permission of Sanchez, P. A. 1976. *Properties and Management of Soils in the Tropics*. London: Wiley.)

How Much Fertilizer is Needed

The farmer can profit from knowing the nutrients taken out of the soil by his different crops. He or she will begin to realize the amount removed in the grain, root, or fruit used; also the nutrient value of the stalks, leaves, and straw that can be left in the field.

Notice, for example, that corn stalks contain much nitrogen and potassium. They will return some of that to the soil if they are left as mulch on the surface. On the other hand, sorghum stalks have very little potassium in the straw.

Knowing plant withdrawals, along with soil test results, can give a picture of fertilizer needs. It can also help the farmer determine which plant materials to put into a compost pile.

The farmer can also get a feel for how much manure or compost will be needed to replace the nitrogen, potassium, and calcium withdrawn in the grain, fruit, and roots.

The following tables show which crops deplete certain nutrients most heavily, that is, how much is removed from the soil. For example, 1 ton of corn grain draws 25 kilograms of nitrogen fertilizer per hectare and 15 kilograms of potassium fertilizer. A 7-ton yield draws 128 kilograms of nitrogen per hectare and 37 kilograms of potassium per hectare. Cassava also feeds heavily on potassium, compared to other nutrients it withdraws.

Caution: The tables are a rough guide and are not meant as a substitute for soil testing where soil testing is possible. They do show the advantage of rotating a crop like corn with a legume like beans that produces nitrogen for its own use, leaves some in the soil, and uses very little potassium.

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Table 1-9. Nutrient Content and Calcium Carbonate (CaCO₃) Equivalence of Commercial Fertilizers

Material	Percentage by Weight						
	N	P2O5	K2O	Ca	Mg	S	CaCO ₃ Equiv.* (pounds per 100 pounds)
Nitrogen Materials							
Ammonium nitrate NH ₄ NO ₃	30	0	0	0	0	0	-59
Ammonium nitrate limestone NH ₄ NO ₃ + (CaCO ₃ + MgCO ₃)	20	0	0	7	4	0.4	4
Ammonium nitrate sulfate NH ₄ NO ₃ + (NH ₄) ₂ SO ₄	26	0	0	0	0	15	-85
Ammonium sulfate (NH ₄) ₂ SO ₄	21	0	0	0.3	0	24	-110
Ammonium thiosulfate (NH ₄) ₂ S ₂ O ₃	12	0	0	0	0	26 —	
Anhydrous ammonia NH ₃	82	0	0	0	0	0	-148
Aqua ammonia NH ₄ OH	16 to 25	0	0	0	0	0	-36 to -54
Calcium cyanamid CaCN ₂	21	0	0	38	0.1	0.3	63
Calcium nitrate Ca(NO ₃) ₂ ·4H ₂ O	15	0	0	19	1.5	—	20
Calcium nitrate/urea Ca(NO ₃) ₂ + 4CO(NH ₂) ₂	34	0	0	10	0	0 -	36+
Crotonylidene diurea (CDU)	32	0	0	0	0	0	—
Diacyandiamide (DCD) C ₂ H ₄ N ₄	65	—	—	—	—	—	—
Isobutylidene diurea (IBDU)	31	0	0	0	0	0	—
Nitrogene solution							
32 percent UAN (35% urea + 45 % A.N.)	32	0	0	0	0	0	-55
30 percent UAN (33% urea + 42% A.N.)	30	0	0	0	0	0	-52
28 percent UAN (30% urea + 40% A.N.)	28	0	0	0	0	0	-49
21 percent AN (60% A.N. + 40% water)	21	0	0	0	0	0	-37
19 percent AN (54% A.N.+ 46% water)	19	0	0	0	0	0	-33

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Percentage by Weight							
Material	N	P2O5	K2O	Ca	Mg	S	CaCO ₃ Equiv.* (pounds per 100 pounds)
Osmocote (available in various formulations)	14	14	14	—	—	—	—
Oxamide C ₂ H ₄ N ₂ O ₂	31	—	—	—	—	—	—
Potassium nitrate KNO ₃	13	0	44	0.6	0.4	0.2	26
Sodium nitrate NaNO ₃	16	0	0.2	0.1	—	—	29
Triazone C ₃ H ₇ N ₃ O	46	—	—	—	—	—	—
UAN-Ammonium sulfate solutions (N = 25 percent to 28 percent)	25 to 28	0	0	0	0	2 to 3 0	
Urea CO(NH ₂) ₂	46	0	0	0	0	0	-84
Urea (sulfur coated) CO(NH ₂) ₂ +S	36 to 38	0	0	0	0	13 to 16	-118
Ureaformaldehyde	38	0	0	0	0	0	-68
Urea sulfate CO(NH ₂) ₂ H ₂ SO ₄	17	—	—	—	—	20	—
Phosphorus Materials							
Ammoniated superphosphate	3 to 6	18 to 20	0	17	0	12	-7
Diammonium phosphate (DAP) (NH ₄) ₂ HPO ₄	18	46	0	0	0	0	-70
Monoammonium phosphate (MAP) NH ₄ H ₂ PO ₄	11	48	0.2	1	0.3	2.2	-65
Ammonium phosphate nitrate NH ₄ H ₂ PO ₄ NH ₄ NO ₃	27	15	0	0	0	0	-62
Ammonium phosphate sulfate 4NH ₄ H ₂ PO ₄ +(NH ₄) ₂ SO ₄	13 to 16	20 to 39	0.2	0.3	0.1	15	-76 to -113
Ammonium polyphosphate (APP) (NH ₄) ₃ HP ₂ O ₇	10	34	0	0	0	0	—
Basic slag 5CaOP ₂ O ₅ SiO ₂	0	2 to 17	0	3 to 33	3	—	70

Ch 1: Soil- The Sustainer of Life

Percentage by Weight							
Material	N	P205	K2O	Ca	Mg	S	CaCO ₃ Equiv.* (pounds per 100 pounds)
Concentrated superphosphate Ca(H ₂ PO ₄) ₂ ·H ₂ O	0	42 to 50	0.4	14	0.3	1.4	0
Ordinary superphosphate Ca(H ₂ PO ₄) ₂ ·H ₂ O+CaSO ₄	0	18 to 20	0.2	20	0.2	12	0
Nitric phosphate	14 to 22	10 to 22	0	8 to 10	0.1	0.3	-15 to -25
Phosphate rock	0	2 to 35	0	—	—	0	10
North Carolina rock	0	31	0	35	0	0	—
Wet-process phosphoric acid H ₃ PO ₄	0	30	0	0	0	0	-63
Concentrated wet-process acid	0	40 to 45	0	0	0	0	-84 to -113
Superphosphoric acid	0	72	0	0	0	0	-109
Urea ammonium phosphate (UAP) CO(NH ₂) ₂ ·NH ₄ H ₂ PO ₄	25	35	0	0	0	0	—
Potassium Materials							
Potassium carbonate K ₂ CO ₃ solid	0	0	48	0	0	0	70 K ₂ CO ₃ liquid
Potassium chloride (Muriate of potash) KCl	0	0	60 to 62	0.1	0.1	0	0
Potassium magnesium sulfate (sulfate of potash magnesia) K ₂ SO ₄ ·2MgSO ₄ /MgSO ₄ ·K ₂ SO ₄ ·6H ₂ O	0	0	22	0	11	23	0
Potassium metaphosphate KPO ₃	0	59	39	0	0	0	—
Potassium nitrate (nitrate of potash) KNO ₃	13	0	44	0.6	0.4	0.2	26
Potassium sulfate K ₂ SO ₄	0	0	50	0.7	1	18	0
Calcium Materials							
Calcium chloride CaCl ₂	0	0	0	36	0	0	0
Burned lime, calcium oxide CaO	0	0	0	70	0	0	178

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Percentage by Weight							
Material	N	P205	K20	Ca	Mg	S	CaCO ₃ Equiv.* (pounds per 100 pounds)
Calcitic limestone CaCO ₃	0	0	0.3	32	3	0.1	90 to 100
Dolomitic limestone CaCO ₃ +MgCO ₃	0	0	0	21 to 30	6 to 12	0.3 95 to 108	
Selma chalk	0	0	0	32	0	0	80
Gypsum CaSO ₄ .2H ₂ O	0	0	0.5	22	0.4	17	0
Hydrated lime (Slaked lime) Ca(OH) ₂	0	0	0	50	0	0	136
Magnesium Materials							
Dolomitic limestone CaCO ₃ +MgCO ₃	0	0	0	21 to 30	6 to 11	0.3	95 to 108
Magnesium ammonium phosphate MgNH ₄ PO ₄ .6H ₂ O	8	40	0	0	15	0	—
Magnesium oxide (Magnesia) MgO	0	0	0	0	45	0	250
Magnesium sulfate (Epsom Salt) MgSO ₄ .7H ₂ O	0	0	0	2	10	14	0
Magnesium sulfate (Kieserite) MgSO ₄ .H ₂ O	0	0	0	0	17	23	0
Potassium magnesium sulfate (sulfate of potash magnesia) K ₂ SO ₄ .2MgSO ₄	0	0	22	0	11	23	0
Sulphur Materials							
Ammonium sulfate (NH ₄) ₂ SO ₄	21	0	0	0.3	0	24	-110
Ammonium thiosulfate (60 percent sol) (NH ₄) ₂ S ₂ O ₃	12	0	0	0	0	26 —	
Elemental sulfur (S): Wettable S	0	0	0	0	0	90 to 100	-312
Elemental sulfur (S): Flowable S	0	0	0	0	0	52 to 70	-218
Elemental sulfur (S): Flowers of S	0	0	0	0	0	90 to 100	-312
Gypsum CaSO ₄ .2H ₂ O	0	0	0.5	22	0.4	17	0

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Material	Percentage by Weight						
	N	P205	K2O	Ca	Mg	S	CaCO ₃ Equiv.* (pounds per 100 pounds)
Magnesium sulfate (Epsom Salt) MgSO ₄ ·7H ₂ O	0	0	0	2	10	14	0
Potassium magnesium sulfate K ₂ SO ₄ ·2MgSO ₄	0	0	22	0	11	23	0
Potassium sulfate K ₂ SO ₄	0	0	50	0.7	1	18	0
Sulfuric acid H ₂ SO ₄	0	0	0	0	0	20 to 33	-62 to -102
Sulfates of Cu, Fe Mn and Zn	(see Micronutrient section)						

*Approximate CaCO₃ equivalent in pounds per 100 pounds of material. Negative value indicates a net acidifying effect on soil; positive value indicates a net basic reaction in soil.

**Do not blend with superphosphate.

Source: North Carolina State University. 2014.

Table 1-10. Nutrient Concentration of Micronutrients

Material	Concentration
COPPER (Cu) MATERIALS	Percent Cu
Copper chelates	
Cu EDTA	13
CU HEDTA	9
Cupric ammonium phosphate Cu(NH ₄)PO ₄ ·H ₂ O	32
Copper sulfate	
CuSO ₄ ·H ₂ O (monohydrate)	35
CuSO ₄ ·5H ₂ O (pentahydrate)	25
CuSO ₄ ·3Cu(OH) ₂	13 to 53
Ammonia base liquid CuSO ₄	8
Copper frits	40 to 50
Copper polyflavonoid	6
Malachite CuCO ₃ ·Cu(OH) ₂	57
Azurite 2CuCO ₃ ·Cu(OH) ₂	55
Cuprous Oxide Cu ₂ O	89
Cupric Oxide CuO	75
Chalcopyrite CuFeS ₂	35

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Material	Concentration
Chalcosite Cu_2S	80
Cupric acetate $\text{Cu}(\text{C}_2\text{H}_3\text{O}_2)_2 \cdot \text{H}_2\text{O}$	32
BORON (B) MATERIALS	Percent B
Borax (sodium tetraborate decahydrate) $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$	11
Boric acid (H_3BO_3)	17
Boron frit/sodium borosilicate	17
Calcium borate (Colemanite) $\text{Ca}_2\text{B}_6\text{O}_{11} \cdot 5\text{H}_2\text{O}$	10
Fertilizer borate (sodium tetraborate) Borate granular ($\text{Na}_2\text{B}_4\text{O}_7 \cdot 5\text{H}_2\text{O}$) Borate 48	14.3 14.9
Magnesium borate (boracite) $2\text{Mg}_3\text{B}_8\text{O}_{15} \cdot \text{MgCl}_2$	21
Solubar $\text{Na}_2\text{B}_8\text{O}_{13} \cdot 4\text{H}_2\text{O}$	20.5
IRON (Fe) MATERIALS	Percent Fe
Basic slag	10 to 13
Ferric sulfate $\text{Fe}_2(\text{SO}_4)_3 \cdot 9\text{H}_2\text{O}$	20
Ferrous sulfate $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$	20
Ferrous ammonium sulfate $(\text{NH}_4)_2\text{SO}_4 \cdot \text{FeSO}_4 \cdot 6\text{H}_2\text{O}$	14
Ferrous ammonium phosphate $\text{Fe}(\text{NH}_4)\text{PO}_4 \cdot \text{H}_2\text{O}$	29
Ferrous oxalate $\text{FeC}_2\text{O}_4 \cdot 2\text{H}_2\text{O}$	30
Ferrous carbonate $\text{FeCO}_3 \cdot \text{H}_2\text{O}$	42
Iron chelates Fe DTPA Fe EDTA Fe EDDHA Fe HEDTA	10 9 to 12 6 5 to 9
Iron lignosulfonate	5 to 11
Iron polyflavonoid	6 to 10
Iron frits	40
Iron methoxyphenylpropane FeMPP	5
Ferrous oxide FeO	77
Ferric oxide Fe_2O_3	69
Iron ammonium polyphosphate $\text{Fe}(\text{NH}_4)\text{HP}_2\text{O}_7$	22
MANGANESE (Mn) MATERIALS	Percent Mn

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Material	Concentration
Basic slag	1 to 3
Manganous oxide MnO	41 to 68
Manganese methoxyphenylpropane MnMPP	10 to 12
Manganese frits	10 to 25
Manganese chloride $MnCl_2$	17
Manganese carbonate $MnCO_3$	31
Manganese oxide MnO_2	62 to 70
Manganese sulfate $MnSO_4 \cdot 3H_2O$	24
Manganese chelate Mn EDTA	12
Manganese ammonium phosphate $Mn(NH_4)PO_4 \cdot 6H_2O$	28
Manganese polyfavonoid	8
MOLYBDENUM (Mo) MATERIALS	Percent Mo
Ammonium molybdate $(NH_4)_6Mo_7O_{24} \cdot 4H_2O$	uo to 54
Sodium molybdate $Na_2MoO_4 \cdot 2H_2O$	38 to 46
Molybdenum frit	30
Molybdenum trioxide MoO_3	60
Molybdenum sulfide MoS_2	60
ZINC (Zn) MATERIALS	Percent Zn
Zinc carbonate $ZnCO_3$	52
Zinc frits (silicates)	varies
Zinc phosphates $Zn_3(PO_4)_2$	51
Zinc chelate Na2Zn EDTA NaZn NTA NaZn HEDTA	9 to 14 13 9
Zinc ammonium phosphate $Zn(NH_4)PO_4 \cdot H_2O$	34
Zinc sulfate $ZnSO_4 \cdot H_2O$	22 to 36
Zinc sulfide (sphalerite)	61
Zinc oxide ZnO	78 to 80
Zinc lignosulfonate	5 to 12
Zing polyflavonoid	7 to 10

Table 1-11. Nutrient Content of Organic Materials

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Percentage by Weight							
Material	N	P2O5	K2O	Ca	Mg	S	Cl
Apple pomace	0.2	—	0.2	—	—	—	—
Blood (dried)	12 to 15	3.0	—	0.3	—	—	0.6
Bone meal (raw)	3.5	22.0	—	22.0	0.6	0.2	0.2
Bone meal (steamed)	2.0	28.0	0.2	23.0	0.3	0.1	—
Brewers grains (wet)	0.9	0.5	—	—	—	—	—
Common crab waste	2.0	3.6	0.2	—	—	—	—
Compost (garden) varies with components and amendments							
Cotton waste from factory	1.3	0.4	0.4	—	—	—	—
Cottonseed hull ash	0	—	27.0	—	—	—	—
Cottonseed meal	6 to 7	2.5	1.5	0.4	0.9	0.2	—
Cotton motes	2.0	0.5	3.0	4.0	0.7	0.6	—
Cowpea forage	0.4	0.1	0.4				
Dog manure	2.0	10.0	0.3	—	—	—	—
Eggs	2.2	0.4	0.2	—	—	—	—
Egg shells (burned)	—	0.4	0.3	—	—	—	—
Egg shells	1.2	0.4	0.2	—	—	—	—
Feathers	15.3	—	—	—	—	—	—
Fermentation sludges	3.5	0.5	0.1	7.3	0.1	—	—
Fish scrap (acidulated)	5.7	3.0	—	6.1	0.3	0.2	0.5
Fish scrap (dried)	9.5	6.0	—	6.1	0.3	0.2	1.5
Fly ash:							
coal	0.3	—	0.1	0.48	—	—	—
wood	0.1	0.6	10.0	9.8	0.66	—	—
Frittercake:							
enzyme production	—	2.2	0.5	—	—	—	—
citric acid production	—	2.0	0.3	—	5.2	—	—
Garbage tankage	2.5	1.5	1.0	3.2	0.3	0.4	1.3
Greensand	—	1 to 2	5.0	—	—	—	—
Grape skins (ash)	—	3.6	31.0	—	—	—	—
Hair	12 to 16	—	—	—	—	—	—

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Percentage by Weight							
Material	N	P2O5	K2O	Ca	Mg	S	Cl
Hay:							
legume	3.0	1.0	2.4	1.2	0.2	0.3	—
grass	1.5	0.5	1.9	0.8	0.2	0.2	—
Leather (acidulated)	—	7 to 8	—	—	—	—	—
Leather (ground)	10 to 12	—	—	—	—	—	—
Leather scrap (ash)	—	2 0.4	—	—	—	—	—
Milk	0.5	0.3	0.2	—	—	—	—
Oak leaves	0.8	0.4	0.2	—	—	—	—
Peanut hull meal	1.2	0.5	0.8	—	—	—	—
Peanut meal	7.2	1.5	1.2	0.4	0.3	0.6	0.1
Peat/muck	2.7	—	—	0.7	0.3	1.0	0.1
Pine needles	0.5	0.1	—	—	—	—	—
Poultry processing:							
DAF sludge	8.0	1.8	0.3	—	—	—	—
Potato tubers	0.4	0.2	0.5	—	—	—	—
Potato, leaves & stalks	—	0.6	0.2	0.4	—	—	—
Potato skins, raw ash	—	—	5.2	27.5	—	—	—
Sawdust	0.2	—	0.2	—	—	—	—
Sea marsh hay	1.1	0.2	0.8	—	—	—	—
Seaweed (dried)	0.7	0.8	5.0	—	—	—	—
Sewage sludge (municipal)	2.6	3.7	0.2	1.3	0.2	—	—
Shrimp heads	7.8	4.2	—	—	—	—	—
Shrimp waste	2.9	10	—	—	—	—	—
Siftings from oyster shell mound	0.4	10.4	0.1	—	—	—	—
Soot from chimney flues	—	0.5 to 11	—	1.0	0.4	—	—
Soybean meal	7.0	1.2	1.5	0.4	0.3	0.2	—
Spanish moss	0.6	0.1	0.6	—	—	—	—
Spent brewery yeast	—	7.0	0.4	0.3	0.04	0.03	—
String bean strings & stems (ash)	—	5.0	18.0	—	—	—	—

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Percentage by Weight							
Material	N	P2O5	K2O	Ca	Mg	S	Cl
Sweet potato skins boiled (ash)	—	3.29	13.9	—	—	—	—
Sweet potatoes	0.2	0.1	0.5	—	—	—	—
Tankage	7.0	1.5	3 to 10	—	—	—	—
Textile sludges	2.8	2.1	0.2	0.5	0.2	—	—
Wood ashes	0.0	2.0	6.0	20.0	1.0	—	—
Wood processing wastes	—	0.4	0.2	0.1	1.1	0.2	—
Tobacco leaves	4.0	0.5	6.0	—	—	—	—
Tobacco stalks	3.7	0.6	4.5	—	—	—	—
Tobacco stems	2.5	0.9	7.0	—	—	—	—
Tomatoes, fruit	0.2	0.1	0.4	—	—	—	—
Tomato leaves	0.4	0.1	0.4	—	—	—	—

Note: Approximate values are given. Have materials analyzed for nutrient content before using.

How to Help the Farmer with Soil Fertility Needs

If commercial fertilizers are available to the farmer at affordable prices, and soil-testing laboratories are available, help take soil samples and send them to a soils laboratory for testing. Be sure to specify the crops to be grown.

Even if the farmer cannot afford or obtain commercial fertilizer, show him or her how to take samples and send them to the laboratory. He or she will still need to know how much organic fertilizer, manure, and compost the soil needs. Again, this assumes a laboratory is available.

In some countries, the extension service or soils laboratory will give you recommendations and amounts of fertilizer to apply per hectare.

If no soil-testing laboratory is available, you can find helpful instructions in Appendix A.

Remember that the farmer must cycle as much organic matter as possible back into, or on top of, the soil. It should be remembered that returning crop residues and some manure back to the soil from which it came might help maintain soil fertility, but does not build it. Where soils are naturally low in nutrients, considerable additional nutrients must be added. Check Table 18 for estimates of nutrients removed from the field by crops and Table 1-9, Table 1-10, and Table 1-11 for contents of nutrient organic fertilizers.

Steps for Soil Testing

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In collecting a soil sample, the farmer will find that getting a truly representative sample of his or her field's topsoil fertility condition requires much care. He or she will need to collect an accurate composite sample, which represents fertility conditions in various parts of his/her field (covering one-half hectare or more).

The farmer should test his/her soil every second or third year.

He or she should take the sample long before planting time, allowing time for the sample to reach the laboratory for the analysis and recommendations, and for fertilizer to be purchased and readily available several weeks before planting time. Following are the steps for soil testing.

How to Take a Soil Sample

Collect the Sample

If the farmer's land is divided into both hillside and bottomlands, treat them as two different fields. The farmer should take representative composite samples of each one, with 15 to 20 subsamples from each field. He or she will send two separate composite samples to the laboratory, one for the hillside field and one for the bottomland field.

Take 15 to 20 small, individual, vertical samples from the crop rooting depth of the soil in each field. This is usually a depth of 15 to 25 centimeters. Take the samples randomly across the entire field. These samples can be taken with a special soil auger so that a sample of 3 centimeters in diameter and 25 centimeters in depth is collected. Or take a similar sample with a spade, shovel, or hoe.

If you are using a shovel, dig the holes 25 centimeters deep to expose a vertical wall. Then push the shovel down vertically, taking a slice 3 centimeters thick from the wall for the full depth. As you lift it from the hole, keep the layer of soil intact in the shovel by bending the shovel handle backward toward you until the soil is level.

Take the 3-centimeter thick layer of soil (which is still held level in the shovel to keep it from sliding out), and remove all soil from the shovel except a vertical center strip 3 centimeters wide by 3 centimeters thick, extending the length of the shovel blade.

This single sample contains an equal amount of soil from each unit of depth. Take this individual sample and place it by itself in a clean bucket. Mix it very thoroughly.

Repeat this process at 15 or 20 random locations across the field. As you collect individual samples, mix each one, and then add them to the total composite sample, also mixing that well. Be sure this large, total composite sample (15 to 20 subsamples) is mixed very

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thoroughly. Take extreme care that all clods are broken, all stones removed, and the soil is uniform and smooth.

Make a Map and Record of the Farm

Show where the samples were taken. Describe the field, the slope, etc., and include a brief crop history (crops grown last year, amount of fertilizer used the last two years, etc.). Indicate the crops to be grown the coming season. Write this information on the same sheet as the map, on the bottom or on the back. Write the farmer's name, address, and the date on the map. Also write the name of the technician who assisted with taking the sample.

Make a copy of the map and all the information for the farmer to keep in a file (a good way to begin teaching the farmer how to keep records).

Deliver the Jar and the Map to the Laboratory

Take the required amount for the laboratory (usually two or three normal cups full). Place it in a suitable carton or clean glass jar and label it with the farmer's name, address, and date.

Introduction

Hundreds of millions of tropical smallholders struggle to produce enough food for their families. Most of them farm very small plots of land, one-half to two hectares, often on steep slopes. Too often the soil is infertile or shallow or both.

Severe erosion steals the life-giving topsoil every time a strong rainstorm hits these hillside fields. If the soil is unprotected, many farms can lose 3 centimeters of topsoil annually and more than 6 centimeters in severe storm years.

Seventy-five percent of the roots of food crops of hill farms are in the top 25 centimeters of soil. They obtain much of the needed plant food and soil moisture from this limited layer. If the top 25 centimeters washes off, the family must soon abandon the land.

Researchers and field workers have been studying erosion for most of the 20th century. They have revolutionized our understanding of what causes erosion and have given us new techniques to fight it. Many of these techniques can increase crop production at the same time. Even the poor smallholder can afford to use the new methods.

In this chapter, we will look at erosion itself. Please study this chapter carefully. It gives you the basic, proven concepts you will need in order to adjust conservation methods to many different farming conditions you will encounter. It may well be the single most important chapter in the entire book.

Definition of Soil Erosion by Water

Soil erosion by water is the force of water dislodging soil particles and transporting them elsewhere. The deposit may be left on the same field, or several kilometers away, or at some very distant point (once it reaches a large stream).

Types of Erosion by Water

The four major types of soil erosion by water are raindrop splash erosion, rill erosion, gully erosion, and stream bank erosion.

Raindrop Splash Erosion

Early conservationists used to call this sheet erosion. Since it does not leave rills or scars on the soil surface, they thought that water running over the surface in sheets had gently removed the soil particles.

Ch 2: Soil Erosion by Water

We now know that the great force of individual large raindrops splashing the soil initiates erosion. This type of erosion is widespread. In fact, the energy of raindrop splash is the main mechanism of erosion. However, good management can successfully handle or prevent it.

Rill Erosion

This is caused by raindrop splash plus relatively large amounts of rainfall water flowing on the soil surface and finding escape routes down the hillside. Water flows to the lowest place, however small the depression. Since the field soil surface is not completely smooth, water will seek the low places. This water is the system that carries away soil particles. Soon more and more water gathers, building up greater depths and speed, forming small channels as it carries soil particles away. It begins to leave micro-gullies called rills. As raindrops continue to fall and splash, the micro-gullies cut deeper. Each successive rain contributes to the micro-gully system. Unchecked, it continues to build throughout the crop-growing season. Some simple, inexpensive methods can prevent this.

Gully Erosion

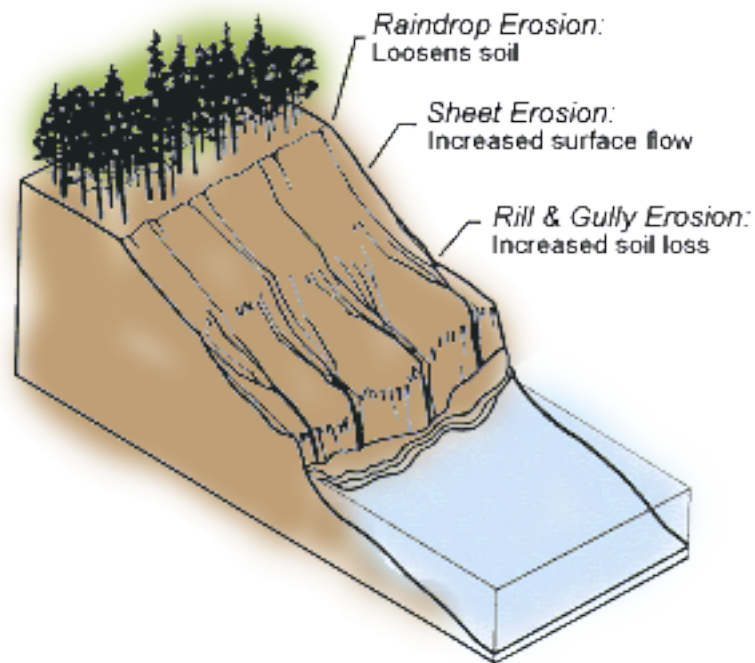
Hydraulic forces of large volumes of deeper rainwater running swiftly downhill can carve out gullies. Storm after storm deepens the cuts. Ultimately, if unchecked, another Grand Canyon is in the making! Much smaller gullies, however, cause serious and increasing damage. Here again, some simple, inexpensive methods can prevent this. The best gully control is prevention!

Note that rill erosion and gully erosion take place only after the raindrop splash has initiated the erosion.

Stream Bank Erosion

Swift running water in creeks and rivers can undercut stream banks. Large volumes of water in gullies may also cause gully banks to undercut and fall into the water.

Figure 2-1. Types of Soil Erosion



Six Factors Affecting Erosion

Erodibility of the Soil

Soils of different types and textures vary in their susceptibility to rainfall erosion. Some types of soil erode more easily than others. The ease of erodibility of different soils is hard to predict without actually seeing them. As a rule, sandy-silty soils and many other soils with poor structure erode.

Soils with good structure have adequate pore space and connected internal channels for water to penetrate rapidly instead of running off the surface. Organic matter in the soil greatly improves soil structure.

Experimentally measured soil erodibility factors mentioned above have been determined, and good estimates have been made in other countries. They vary from 0.00 to 0.69 (with the highest number being the most erodible). For tropical soils, the range is believed to be from 0.00 to 0.55.

In the tropics, the more weathered soils tend to be more resistant to erosion than the less weathered soils. These more weathered soils usually have good structure that is resistant to raindrop forces tearing soil particles free. Their infiltration rates (the rates at which water flows into and through them) are much higher. This reduces the amount of water running off the field.

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Some studies show that more weathered soils may have infiltration capacities of more than 200 millimeters of rainwater per hour, while some less weathered soils have infiltration capacities of less than 20 millimeters per hour. During a heavy rainstorm much more water will run off the surface of the soils with low infiltration rates and much more erosion will occur.

As you drive or walk along roads and trails in your host country, look for differences in soils and the amount of soil erosion, especially after a storm. Which soils seem eroded most? Be wary, however, because the way the farmer uses the land may often overshadow soil types as the chief cause of erosion. Hopefully, your Peace Corps Volunteer (PCV) agricultural specialist will have some local soils information to share with you.

Rainfall Intensity and Amount

We now know that raindrop splash energy is the chief agent in erosion. If the soil is not covered, a large raindrop acts like a small bomb. It gouges out a crater, dislodges the soil, and splashes it into the air. This is the beginning of soil erosion. When millions of very large raindrops hit the bare ground, they dislodge many millions of soil particles. They force soil particles apart from each other with detonating action, and slash them upward and outward. The runoff rainwater carries the loosened particles away. Raindrops continue to pound the surface, tearing more particles free from newly exposed soil.

The lighter, smaller soil particles go first. In other words, clay particles and organic matter particles in the soil surface splash away. These contain most of the plant nutrients in the upper fraction of topsoil. You recall that organic matter also creates good soil structure. When many of the most valuable parts of the topsoil continue to splash out and wash away, the upper soil surface pays the price, resulting in poorer structure.

Large drop rainfall impact can seal the soil's surface. Besides detonating and loosening particles, raindrops pound, then splash and mix the wet soil into slurry. The raindrops' splash makes a paste on the surface of the soil. It begins to fill and seal soil air and water pores, partially restricting rainwater entry into the soil. This greatly increases rainwater runoff and soil erosion.

When the soil surface, now of poor texture, dries, it forms a crust, which may impede the emergence of sprouting crop seed. In addition, the hard soil crust will accelerate water runoff during the next rainstorm.

The following shows a large raindrop landing on unprotected soil, making a relatively deep hole and splashing soil particles up and away from the point of impact. Other drops will dig the hole even deeper.

Figure 2-2. Raindrop Splash



Steepness of Slope

The amount of erosion enlarges dramatically with increased steepness of the hillside (higher percent of slope). Increasing steepness of slope increases the speed of flowing water. Swiftly flowing water transports much more soil than slow-moving water. It quickly sweeps away soil dislodged by rainfall splash. Any practice that reduces the steepness of the slope will reduce the rate of water runoff and the soil erosion.

The following table shows soil erosion measured in three different locations and different soils under different but comparable rainstorms. All measurements were taken on bare soil fully exposed to the storm.

Table 2-1. Tropical Soil Erosion Studies with Different Soils, Different Rainstorms, and Different Slopes in Different Countries

Bare Soil	Slope	Erosion Soil Loss (metric tons/hectare/year)
Trinidad		
Sandy clay loam (very high infiltration rate—resistant to erosion)	11 percent	13 tons/hectare/year
	22 percent	35 to 49 tons/hectare/year
	52 percent	68 tons/hectare/year
Indonesia		
Three different soils, all highly erodible	3.5 percent	100 tons/hectare/year
	9 percent	469 tons/hectare/year
	10 percent	415 tons/hectare/year
	14 percent	532 tons/hectare/year

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Bare Soil	Slope	Erosion Soil Loss (metric tons/hectare/year)
India		
Moderately erodible	.5 percent	3 tons/hectare/year
	1.0 percent	10 tons/hectare/year
	3.0 percent	14 tons/hectare/year

Source: Suwardjo et al.; Uumbs et al.; and Dhruva et al. 1983. Combined and modified from the International Conference on Soil Conservation.

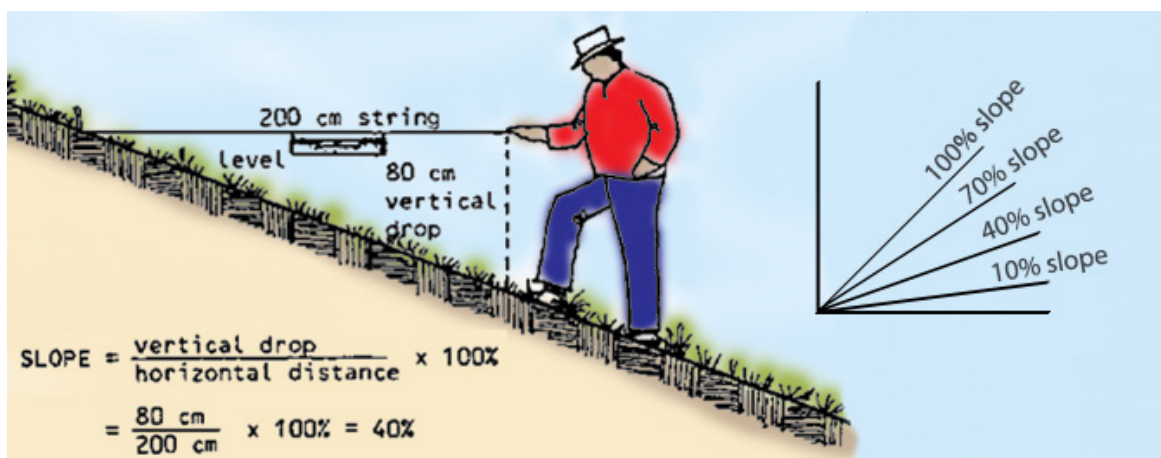
The Indonesian soil lost 532 tons per hectare per year at a 14 percent slope—a very moderate slope among hill farmers who often farm 60 percent slopes. The 532 tons of erosion per hectare takes away a layer of topsoil 48 millimeters thick, a tremendous loss of soil fertility and water storage capacity. Remember that, in order to maintain a sustainable system, a farm should not lose more than 10 or 11 tons per hectare per year of topsoil depth. Land without much topsoil cannot afford to lose even that amount.

Agricultural specialists need much more field research dealing with management of extremely steep slopes (those above 40 percent). An increasing number of small farms occupy slopes of 60 percent or more.

Erosion increases with increasing slope, even with great variation in erosivity of the soil.

In the following figure, think of each line as the actual slope of a field. Steepness increases as you go from 0 to 10 percent, to 40 percent, to 70 percent, and to 100 percent. Note that a 100-percent slope line is at a 45-degree angle with the horizontal line.

Figure 2-3. Visualizing Percent Slope



In order to maintain a sustainable system, a farm should not lose more than 10 or 11 tons per hectare per year—about 1 millimeter per year of topsoil depth.

Length of Slope

Under most conditions, increasing the length of the slope in the field increases soil erosion, but not as fast as increasing the steepness of slope. However, it is critical to keep length of slope within reasonable length. Longer slopes encourage rill erosion to occur. If neglected, this generates gully erosion.

Appropriate field contour ditches, dead or live barriers, or a combination of these can change the length of the slope. Some form of bench terrace can change both the percent and the length of the slope. See Chapters 3 and 4 for detailed methods and for spacing between contour ditches or individual barriers.

Land Management Practices

Conservation land management practices being used (or not used) help determine the amount of erosion from a farmer's field. A farmer who plows and plants up and down the slopes creates ready-made pathways for runoff water to carry soil away quickly, and for gullies to form. Good management begins by installing contour drainage ditches and plowing and planting rows on the contour (i.e., placing the rows and ditches perpendicular to the direction in which the water, pulled by the force of gravity, runs down the slope).

Crop Management Practices

The farmer can protect the soil by covering it with growing vegetation, crop residues, etc.—the thicker, the better! This keeps the rainfall from beating the soil. Small farmers can effectively and inexpensively save their soil by protecting it from large raindrops. You will find many crop management techniques and ways to teach them to farmers in Chapters 3 and 4.

Special Note on Raindrops

Raindrop energy from large raindrops is the main driving force behind erosion. Erosion is a work process requiring a lot of energy—tearing the soil particles loose, bouncing them high into the air, pounding the runoff water and the newly exposed soil and water mix, helping push the runoff water down the hill, stirring up the runoff water, scouring the soil, and transporting away the particles. The major source of energy for all of this is large raindrops. The energy from large raindrops is many times greater than from the equivalent amount of water running on the soil surface.

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Classic Raindrop Experiment

Norman Hudson conducted some of the most significant experiments in the tropics. He stretched wire mosquito netting across small plots of bare soil and suspended these a few centimeters above the soil surface. He left other similar plots of bare soil without cover. After several heavy rainstorms, the soil loss from the bare soil plots without the mosquito net was 100 times higher than from the plots protected with netting. The water runoff was also much greater from the bare soil plot. Plots covered with grass mulch provided the same results as the plots covered with the wire netting. Both netting and grass mulch absorbed the rainfall impact energy and the soil was not dislodged to cause significant erosion.

The same amount of water hit the soil in all three plots. However, the covering on the plots broke the large drops into small ones, resulting in a rainfall of very gentle force. In the plots without the cover, the soil absorbed the full energy from the large raindrops and was heavily eroded.

Source: Hudson. 1995.

Effects of Raindrop Size

Large raindrops (raindrop splash energy) are usually the main culprits of erosion. Larger raindrops hit the earth with greater force.

The size of raindrops in different storms varies greatly. Storms with larger raindrops cause the most erosion. The more intense the rainstorms, the larger the raindrops and the more energy contained in the rainfall.

Hudson (1995) calculated the kinetic energy of intense rainfall as compared to that of water runoff. He showed that, under his given conditions, large raindrops with a terminal velocity of 8 meters per second could have 256 times as much kinetic energy as the runoff water flowing on the surface at 1 meter per second.

Effect of Raindrop Terminal Velocity

Terminal velocity is the maximum speed a falling raindrop can reach. Bodies falling through the air accelerate from the pull of gravity. They accelerate until the friction of the air balances the pull of gravity. At this point they have reached terminal velocity. They will strike the earth at this speed. They will never fall any faster. Large raindrops (up to 5-6 millimeters in diameter) fall at 8-9 meters per second—much faster than small raindrops.

A raindrop with high terminal velocity hits the soil with a much stronger force than one with low terminal velocity. The larger drops are much heavier. They reach a higher speed and have

much greater force than small drops. Billions of larger drops will be heavy enough and will travel fast enough at terminal velocity to detonate the soil on impact. Intense storms, which contain mostly large raindrops reaching high terminal velocities, cause heavy soil loss.

Even though the leaves and branches of tall trees deflect the rainfall and break up the size of the drops, large drops reform on the leaf surfaces and fall again, hitting the soil surface at terminal velocity. In a forest, low-growing vegetation and litter on the ground do more to fight erosion than the leaves growing on tall trees.

Special Note on Water Runoff

Water runoff is the excess water that runs off the land during and immediately after a rainstorm. It is the percent of a specific storm's rainfall, the amount of rainwater, which did not soak into the soil. It is measured in millimeters and expressed as a percentage of the total rainfall for a given rainstorm or for a given period of time.

Water runoff transports away hundreds of tons of soil particles torn free from the soil by rainfall splash. Some of these soil particles may stay on the farmer's field but a great majority leaves the farm unless controlled. If farmers do not handle runoff water properly, its hydraulic force digs gullies in their farms. Over time, if left uncontrolled, together with "rainfall splash," it can turn farmers' fields into wasteland. However, water runoff, if handled properly, can often be beneficial (see table)

Table 2-2. Drawbacks and Possibilities of Water Runoff

Drawbacks	Possibilities
<ul style="list-style-type: none">• Transports away soil particles and plant nutrients; as runoff increases, erosion increases• Scours the soil and creates gullies from its hydraulic force• Can cause floods when combined with runoff from other farmers' fields• Can plug streams and reservoirs with silt	<ul style="list-style-type: none">• With proper control, can be channeled into ditches and ponds, provide irrigation water, and keep much of the soil sediment on the farm• Can be channeled or stored for useful purposes• Can replenish streams, ponds, and reservoirs with clean, useable water if flow is controlled and run over grass sods, which keep it clean• Can be stored in pond, which make possible a constant water supply for the farm family, animals, irrigation water, and fish culture (The Peace Corps has successfully deployed fish culture projects using ponds charged with runoff water. This has been an economic incentive for farmers to construct and maintain waterways, catchment ponds, and larger reservoirs.)

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Factors Affecting Runoff

All of the following influence the amount of water that will run off a field during a rainstorm.

Intensity of Rainfall and Duration of Storms

The intensity of rainfall (how hard it rains) determines the rate of water downpour and, therefore, the amount and rate of runoff. A light rain of 15 millimeters per hour might not cause runoff, whereas a heavy rain of 50 millimeters per hour definitely would.

Infiltration Rate of the Soil

The faster the soil soaks up the rainwater, the less water remains to run off the farmer's field.

When a rain begins, all water goes into the soil until the rain falls faster than the soil can absorb it. Then it begins to run downhill.

The infiltration rate of different soils varies, but it is relatively high for many of the tropical soils if the soil surface is covered with grass or mulch.

However, if the soil is bare, the runoff will probably be heavy. If the soil is bare, large raindrops pound the soil surface; destroy the soil structure; and partially seal the surface, plugging the soil air and water space. This reduces the infiltration rate. Water runoff and erosion increase.

If the soil profile is already saturated, all of the incoming rainfall will run off.

Soil compaction also influences water infiltration. During a heavy rain, look at the runoff on a compacted surface, such as a foot path, an unpaved dirt road, or the area around a livestock water hole where animals have trampled the soil. Notice that the rainwater immediately runs off all such compacted soil surfaces. This is because the soil structure is destroyed. The air-water passages are plugged.

In Figure 2-4 below, the soil with good structure (top) has many pores and passageways for rainwater to enter and pass through to the subsoil. The compacted soil (bottom) has poor structure and limited pore space, which means that little water can infiltrate or pass through.

Figure 2-4. Soil Compaction

Photo c/o creativecommons.org



Depth of Topsoil and Subsoil

Different soils and soil types vary greatly in their ability to retain water. Chapter 1 gives you information on soil structure, the infiltration capacity of different soils, their water holding capacities, and some pointers on how to recognize them.

Slope of the Land

As one would expect, the higher the percent of slope, the greater the runoff (other factors being equal). On a steeper slope, the water does not have as much time to soak into the soil, so it runs off more quickly.

Vegetation on the Land

Infiltration rate into a given soil will increase if the land is covered with trees (forest with a good cover of leaf litter) or a well-managed pasture with a healthy grass sod, or if a plowed field has a thick grass mulch. With a dense protective vegetative cover, the rainwater percolates quickly into the soil and may not become runoff.

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Farmer's Conservation Practices

As with erosions, the farmer's land and crop management methods will strongly affect the amount of water runoff.

Land Management Practices

Poor land management practices encourage the flow of water into destructive patterns, i.e., cultivating and leaving bare soil, plowing vertically down the hills, failing to handle runoff, and failing to deal with incipient gullies. Good land conservation practices stop or help slow down the flow of water from the field.

Crop Cultural Practices

Good crop cultural practices help maintain high infiltration rates by keeping mulch or live vegetative cover on the soil surface. They also maintain high fertility so that plants produce abundant soil cover and organic matter. The best case is well-managed conservation tillage.

Poor cultural practices leave the soil bare of vegetation so the rainfall can pound and compact it. The worst case, of course, would be planting row crops up and down the slope of the hill.

Figure 2-5. Erosion Control- Using Low Rock Barriers to Slow the Flow of Water



In the image below, Peace Corps Volunteers and their counterparts create rich, healthy soil by adding charcoal, wood ash, manure, and compost to the fully loosened subsoil, and then protect that soil by covering with mulch.

Figure 2-6. Creating and Protecting Healthy Soil



How to Manage Runoff Water

Whatever the method of erosion control, surplus runoff water must be dealt with. The amount of rainfall, the infiltration rate, erodibility of the soil, and steepness of the slope determine whether the field needs contour drainage ditches and exit drainage ditches. Some drainage control ditches usually need to be installed. Provisions must also be made to handle the runoff from very large rainstorms, which may occur only once in several years.

To help the farmer plan, you will need all the information about local rainfall that you can find.

Cropping plans may help you have the maximum amount of vegetation growing and spreading its leaves, protecting the soil from raindrop splash. The knowledge you obtain from your rainfall calendar will help you set up the most desirable cropping plan. You might use the rainfall data to suggest how traditional planting and harvesting dates can be modified for better conservation. However, this is always a challenge because so many other responsibilities in the farmers' lives can be affected.

Other erosion control practices also depend upon weather knowledge and planning. For example: What is the best time of the year to begin and complete terraces? When should you start contour drainage ditches? When should you have them finished? When should you plant live barriers for best germination and growth? Terraces and ditches should be finished well ahead of the rainy season; seeds need to be planted at the beginning of the first gentle rains.

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How to Make and Use a Rainfall Calendar

1. Check with local farmers, their program managers, and/or host government extension officers for historical rainfall data.
2. Get data for national and area rainfall from the nearest weather station and from your host country's Bureau of Climatology or another appropriate agency. Obtain rainfall intensity data: How much rain falls during peak storms and how much total rainfall is there for each given month? You may be able to locate climate maps and/or tables somewhere or obtain them online at <http://datworldbank.org/indicator/AG.LND.PRCP.MILLIMETERS>
3. Learn all you can about area rainfall and erosion from other PCVs, your Peace Corps (PC) associate director of agriculture, etc.
4. Consult local farmers and village leaders. Learn what they know about rainfall in their local area; this may be the best information you are able to find. When do peak rains fall? How heavy are they (millimeters per hour)? How long is the rainy season? The dry season?
5. Begin keeping your own rainfall record book. Later transfer all pertinent rainfall data to the calendar. (See Appendix A. Basic Tool Kit of Techniques for the Field for instructions on Measuring Rainfall.)
6. Determine the average rainfall for each month of the year and the total annual amount. What seems to be the year-to-year variation?
7. Look at very dry or very wet months. Consider these and the total annual rainfall to understand the local cropping practices and to make plans for soil conservation activities.
8. Determine the length of the dry season and whether the area has one or two wet seasons. With two seasons, do farmers practice double cropping? What different crops are grown?
9. Memorize your bar graph calendar and keep asking questions of farmers and village leaders.
10. How long after the early rains (planting time) do the really heavy rainstorms begin? This is important to know. The longer the crop has been growing, the larger the plants will be and the more they will cover the ground to protect from the raindrop splash of heavy rains.
11. If local rainfall data is not available, begin a long-range rainfall data-gathering project. Get other PCVs from different areas to work with you. Arrange to pass this project on to others when you leave. This is important information. (See Appendix A).

How to Help Farmers with Erosion

Achieve an Acceptable Rate of Erosion

Erosion under natural conditions or geological erosion happens at such a slow rate that, although it has been going on for hundreds of thousands of years, the soil depth actually increases. Soil particles have been formed and accumulated faster than they have been removed. This natural soil-building process will build a 25 millimeters deep topsoil (a layer about 1 inch thick) in about 100 years.

Cultivating this layer in a very careful, ideal way so that no erosion occurs can actually speed up the soil-building process so that only 25 or 30 years is required to build the 25 millimeters. Stirring the soil allows more air (more oxygen) to be available for the soil-forming processes, chemical and biological, to work faster.

If 1 millimeter of soil is being built in a year, 1 millimeter could be lost to erosion and the soil building-soil loss would break even. This might be considered an acceptable erosion rate. One (1) millimeter of topsoil over 1 acre weighs 5 tons, or 11 metric tons per hectare. Therefore, a soil erosion goal for small farmers might ordinarily be to control their soil loss to a 1-millimeter depth per year, or less than 11 metric tons per hectare per year.

Motivate Farmers to Use Erosion Control Methods

Smallholder farmers often exist at a subsistence level. Frequently they and their families stay just one step ahead of starvation. They cannot afford any risk, even of labor, without something extra to show for it.

For long-term success, increased crop yields must accompany erosion control methods. The farmer's crop yields should increase the first year, if possible. If yields have not increased by the second year, you have lost him or her. On the other hand, if yields increase significantly, the farmer will be eager to continue and will proudly demonstrate such successes to his or her neighbors.

Following are two approaches to controlling soil erosion. Both are important. Often the farmer in the tropics needs to combine them to get maximum protection. Farmers should aim for as close to zero erosion as possible if the soil is shallow. Hillside tropical soils are likely to be just that.

Whatever approach you use, keep the farmer's interest focused on the value of the topsoil. Field research around the world has demonstrated that the deeper the topsoil, the higher

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the crop yield; the more topsoil lost to erosion, the smaller the yield. Farmers who realize this relationship will usually be highly motivated to save their soil.

Dissipate Raindrop Splash Energy

With this approach, farmers cover the soil and screen it from the force of raindrop splash. The soil is thus protected from the force of large raindrops and the raindrop energy that initiates erosion. When this is done, erosion usually does not take place.

This approach seeks to prevent the disorder, to keep erosion from occurring in the first place. The farmer keeps a live or dead vegetative cover on the soil whenever possible. He or she can also try many crop management techniques that help do this. Chapter 3 (and later chapters for special situations) will look at ways to combat raindrop splash.

Change the Degree of Slope and Length of Slope

Changing the degree and the length of the slope do not in themselves prevent raindrop splash erosion. They hold the rainfall water in one place after the rain has hit the soil, or they slow down the speed of the runoff, thus minimizing erosion.

This approach treats the symptoms of the disorder by various physical changes to the land. If the farmer can keep the water from running off, or can slow down the speed of the runoff, much of it will soak into the soil. In addition, many of the soil particles held in suspension will have time to settle and drop to the soil surface before they are removed from the farm. Chapter 4 will deal with ways to change the slope (percent slope and length of slope) of the land. It will also discuss drainage ditches in detail.

Control Water Runoff

Whatever the method of erosion control, any surplus runoff water must be dealt with. The amount of rainfall, the slope of the land, and/or the infiltration rate of the soil determine whether or not the field needs contour drainage ditches and exit drainage ditches to handle excess runoff. Some system of ditches for drainage control is usually needed.

Introduction

The benefits of a fertile soil are numerous:

- A fertile soil is a less erosive soil.
- High soil fertility results not only in higher yields, but also in faster plant growth that covers the soil more completely and quickly. Lush, profuse, healthy plant growth makes a thicker cover than sparse, sickly growth.
- Plants grow larger and develop larger leaves sooner. They produce more green matter in tops, stems, and roots to form organic matter and mulch. This, in turn, can improve soil fertility and infiltration rate.
- Plants develop much larger and deeper root systems that search out more nutrients and moisture. This makes them drought resistant.
- Crops can be planted more densely. The farmer can plant many more plants per hectare, thus better covering the soil and increasing yields.

Covering the soil increases soil fertility. This chapter will explain the benefits of a vegetative soil cover and ways to protect the soil with a cover.

Benefits of a Vegetative Soil Cover

Even partial soil cover effectively protects the soil. Research studies show that when even 40 percent of the bare soil surface is covered uniformly, 90 percent of the potential erosion does not occur. Other benefits of soil cover include:

- Forms a protection or screen over the soil, dissipating the force of raindrops
- Decays with time, forming organic matter, improving soil structure, raising the rate of water infiltration, and increasing soil fertility
- Shades the soil, reducing soil temperature, and thus evaporation of soil moisture
- Increases plant root growth because of lower soil temperature and better soil moisture during hot weather
- Produces a net result of increased yields and lessened erosion

Ways to Protect the Soil with a Cover

Mulch

Mulch is composed of dead plant material used alone or in combination with one another. This includes straw, harvest litter, grasses, leaves, manures, and compost.

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Heavy straw mulches (rice straw, wheat straw, dead grasses) completely protect the soil, resulting in zero erosion and increased yields! (However, remember that the extra yields do not materialize unless the soil is very fertile, or made and kept that way. Use recommended amounts of manure, compost, and commercial fertilizer.)

How to Make and Use Mulch

1. Leave the stalks and leaves on the field after the harvest. Find additional mulch: strip leaves from trees growing nearby, bring rice straw from fields in the lowlands to use on sloping fields, and get straw or harvest trash from neighbors. Caution: Do not use diseased plant residues in mulch.
2. Prepare the soil for planting and do not burn the trash. Some of the stalks can be turned under and some left on the surface.
3. Properly fertilize the soil for more crop yield for faster-growing leaves to cover the soil and more organic material for mulch the following year.
4. Cover the soil: Spread compost and available straw, leaves, etc., on the soil surface. Ideally, the mulch should be spread about 10 centimeters thick.
5. Plant through the mulch, using a dibble stick, or if you use a hoe, make a very narrow trench or hole for the seed.

There may be resistance to leaving crop residue on the ground because some farmers believe that leaving a layer of dead material can attract termites, which may have a detrimental impact on the roots of live plants. However, this may also attract predators of termites and other beneficial soil fauna.

Field Litter

Do not burn the fields before planting. Leave crop residues (stalks, leaves, clippings, or trimmings) on the ground after harvest. Leave old plant root stubble in the soil to anchor it.

Conservation Tillage

Conservation tillage is used to describe a number of technologies used to conserve soil. Conservation tillage leaves a nearly undisturbed layer of vegetative cover on the soil at all times. When the farmer plants his or her crops, he or she breaks up the soil as little as possible. He or she leaves most of the soil intact and covered. The farmer tills only a very narrow seedbed, just the minimum space needed to place and mix fertilizer and compost with the soil, and to plant seeds or insert seedlings.

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Conservation tillage provides all the advantages of a good soil cover. In fact, it provides them so well that some farmers can achieve zero erosion. Under the right management, it significantly reduces labor when compared to conventional methods. It makes a cumulative, progressive improvement in the soil organic matter and soil fertility year by year. Conservation tillage can produce substantial increases in crop production, if fertility is adequate.

Methods for conservation tillage vary. The degree of slope of the land (whether steeply sloping or nearly level) and the needs of the farmer determine what modifications are needed. Conservation tillage practices include, among others, strip cropping, contour farming, zero or chemical tillage, mulch tilling, and reduced tillage.

Strip Cropping

Strip cropping is the farming of sloping land in alternate, contoured strips of inter-tilled row crops and close growing grasses (or other ground cover crop), aligned at right angles to the direction of natural flow of runoff. The close-growing strips slow down runoff and filter out soil washed from the land in the inter-tilled row. This control of runoff also allows increased opportunity for infiltration of the runoff and, thus, increased moisture in the soil. The strip widths can be varied depending on the soil type and slope.

A particular form of conservation tillage called “strip cropping” was developed by World Neighbors, a nongovernmental organization (NGO) that focuses on training and educating communities to find lasting solutions for hunger, poverty, and disease. This farming technique works well on hillsides. It is simple and can be carried out with tools the farmers have always used. Thousands of small hillside farmers now use in-row tillage.

Using this method, the farmer digs narrow rows of soil going around the bill on the contour. The rows are 1 meter apart. Each year, he or she cultivates only the same narrow strips and plants his crops in them. He or she leaves space between the contoured rows untilled, covered with native grass, and unfertilized.

The idea is to build up the organic matter, fertility, and soil structure in the narrow cultivated planting rows as the years pass. The soil in them rapidly develops increased rooting depth, superior soil tilt, and good organic matter content, becoming more and more fertile and productive.

The uncultivated part left in native grass (the rest of the 1-meter space) protects the soil from raindrop splash with a good grass cover. At the same time, the matting of grassroots helps hold the soil in place on the hillside. Note: This system works best where soil moisture does not limit plant growth.

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How to do Strip Cropping

Most of the following instructions are based on experience in the field by World Neighbors workers in Honduras and elsewhere. They have been field tested by many hundreds of small-scale tropical farmers under observation.

Since strip cropping is contour farming, the farmers must learn how to construct and use an A-frame device so their contour rows are level (see Appendix A.)

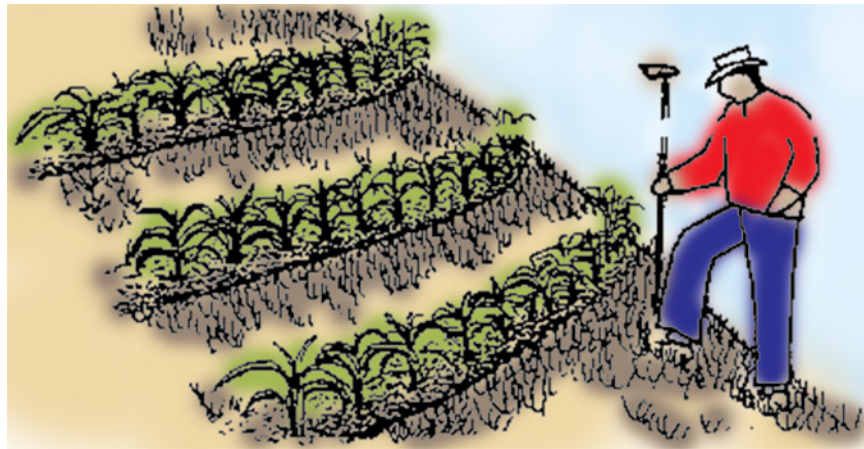
1. As with most erosion control farming schemes, begin work at the top of the slope. Otherwise, floodwater coming from above may destroy your work.
2. During the dry season, construct an upper drainage contour ditch (diversion ditch) at the top of the field to protect the work from floodwaters coming from any neighbor's land above. It should have a 1 percent slope toward the exit drainage ditch.
3. Begin conservation tillage immediately below the ditch. Do not cultivate anything except the narrow planting row.
4. Dig other contour drainage ditches as needed, depending on the rainfall situation, soils, and slope (see Chapter 4.)

Figure 3-1. Conservation Tillage

Photo c/o creativecommons.org



Figure 3-2. Hillside View of Strip Cropping



Advantages of Strip Cropping

- As with other forms of conservation tillage, in-row tillage increases crop yields, usually substantially.
- Organic fertilizer-manure-compost (and recommended chemical fertilizer) is concentrated in the row. Therefore, these bands of soil become extremely fertile—more so each year.
- The fertilizer is not spread widely. This saves fertilizer costs. It feeds crops, not weeds.
- The grass-covered area acts to prevent erosion. The rows (tilled and untilled) become micro terraces (grass-covered).
- Farmer experience shows that minimum (in-row) tillage, once it is established, often requires only half the labor as conventional tillage.
- The farmer can walk easily on the outer edge so he or she can do his/her fieldwork on the contour (whether pruning back the grass, planting the seed, or harvesting). By walking on the outer edge, the farmer does not compact the tilled row by foot traffic.
- Post-harvest trash (leaves and stems of crops) is used instead of waste. Some is chopped and worked into the seedbed. Some is used to cover the freshly planted narrow rows each year.
- It has maximum yields and maximum soil protection from splash erosion.

Contour Farming

Contour farming involves aligning plant rows and tillage lines at right angles to the normal flow of runoff. It creates detention storage within the soil surface horizon and slows down the rate of runoff, thus giving water the time to infiltrate into the soil. The contour bunds are

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earth banks 1.5 to 2.0 meters wide, forming buffer strips at 10- to 20-meter intervals. They are important for the functioning of the technology. The effectiveness of contour farming for water and soil conservation depends on the design of the systems, but also on soil, climate, slope aspect, and land use of the individual fields.

Zero or Chemical Tillage

In this approach, the land is not tilled at all. Chemical tillage uses herbicides to control weeds, avoiding the need to till the soil. This tillage technique conserves water in the soil profile since the soil is not tilled and exposed to the drying (evaporative) elements of the atmosphere. The moisture is retained within the soil profile. The new crop is generally planted directly into the stubble of the previous crop.

Mulch Tillage

Mulch tilling involves covering bare soil with mulch or plant litter to prevent or reduce the evaporation of soil moisture and minimize the erosive energies of rain falling directly onto soil particles. The mulch is usually crop residue, such as maize stover, sorghum trash, and wheat straw. In cases where these are not available or are eaten by animals, gravel can be used as mulch.

Reduced or Minimum Tillage

Reduced tillage is a practice in which the soil is tilled to some extent, but not completely inverted. There are several ways of achieving reduced tillage. For example, the plow can be supplemented with discs or a chisel harrow, and the land plowed in narrow strips, coinciding with the spacing of the row crops, leaving the intervening space untilled. Reduced tillage means a smaller volume of soil is exposed to erosion and moisture loss by evaporation; hence, conserving moisture.

Green Manure Cover Crops

A cover crop has special ground-covering characteristics—the crop spreads widely and quickly, and should have dense, large leaved foliage. It is planted to provide cover for the soil and also to be used as food. It can sometimes be planted by itself to cover bare ground, or in the middle between rows of other crops, or as part of a crop rotation.

In Figure 3-3 below, Peace Corps Volunteers and their counterparts cover the planted seeds with either mulch (left) or neem tree stems (right) to keep the sun from evaporating moisture, enrich the soil, and keep insects away.

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Figure 3-3. Mulch Tillage



Often a cover crop is used as a companion crop. In other words, it grows well with a chosen row crop (such as maize) and is planted between the rows.

Planting row crops in combination with a cover crop works especially well in regions with adequate rainfall. It also is effective if the rainfall pattern allows double-cropping (i.e., growing and harvesting two crops one after the other during the year, as opposed to growing a single crop). Even planting two tall-growing food crops such as maize and cassava together has advantages. Not only is more food produced in the space, but also more leaves are spread over the soil to catch the raindrops and reduce erosion.

One example of a cover crop is a grass (or a grass and legume) sod, which covers the soil in an orchard of fruit, palm oil, or rubber trees. The grass carpet, composed of perennials, covers the soil. If the cover crop is a grass and legume mix, the low-growing legume will produce enough nitrogen for itself and the grass.

When the cover crop is a legume, it is called a green manure cover crop. It has three special characteristics: (1) It acts to intercept rainfall, and thus prevents erosion, since it grows rapidly and is very leafy; (2) It is a legume, which produces much nitrogen fertilizer and a large amount of green organic material to become soil; and (3) It usually produces some family food or animal feed.

The nodules on legume roots house millions of *Rhizobium* bacteria that take nitrogen from the air and make nitrogen fertilizer from it. Nitrogen-fixing legumes can furnish enough nitrogen for their own needs and also return a lot to the soil. Under the right conditions, an excellent legume can produce 20 to 30 tons per hectare of green plant material for organic matter, and 150 to 200 kilograms per hectare of nitrogen fertilizer per year.

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Green manure cover crops serve as a wonderful multipurpose tool. Recommend them if you can find one that works well under local conditions. It may prove to be worth many bags of fertilizer for each farmer.

A green manure crop provides all the benefits of a good soil cover (controls erosion; increases the rate of water infiltration; lowers soil temperature, and thus reduces evaporation).

Figure 3-4. Velvet beans—a Good Green Manure Cover Crop

Photo c/o creativecommons.org



Note: This fast-growing climbing bean spreads out quickly over the soil giving excellent protection in the event of an intense rainstorm. It grows well with corn. When the corn is mature, velvet beans climb over the corn stalks and continue to grow for several weeks, yielding dry beans, green foliage, and extra nitrogen fertilizer.

Benefits of a Green Manure Crop

- Directly improves soil fertility at a rapid rate.
- When used with recommended water and soil conservation methods, yields good food crops, in many cases three to four times the former yield.
- Stimulates growth of organic nitrogen fertilizer on site rather than having to purchase and transport it.
- Produces abundant organic matter. The soil organic matter increases in amount and depth in the fields, increasing root depth and soil fertility.
- Reduces the length of time that depleted land must lie fallow from a number of years to about two or a little more. Note: In some cases, phosphate fertilizer or manure may be needed to establish the green manure crop on very poor soils.

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- Its cost is low. The farmer's only financial cost will be for seed the first year. Seed from the first cover crop can be saved to plant the following year.
- Requires minimal labor. The only labor needed is for weed control. Often the thick, spreading leaves of the cover crops shade out weeds so they cannot grow, reducing labor costs.
- Can shade the soil for up to 11 months (important in tropical climates).

Do Green Manure Crops Reduce the Land Area Available for Food Crops?

If the green manure cover crop is planted properly, the land area is usually not reduced. Planting crops between row crops does not take additional space. (This would not be true with the typical dense planting of corn often found in the United States.) Such row crops as maize and sorghum grow above low-spreading cover crops with no loss of space.

Certain green manure cover crops can grow under or around fruit, nut, or coffee trees, benefiting the trees.

If a fast-growing legume competes with a corn or grain crop too early, the farmer can lightly prune the growing bean tops.

Where farmers ordinarily leave land to lie fallow, or shift to other land, planting green manure cover crops will significantly shorten the time to return the land to productivity.

Even if some minimal land space is initially lost due to intercropping, green manure cropping increases fertility, which in turn soon increases crop yields. The row crop yield usually should not drop, even the first year, unless soil moisture is limited. Yields should increase substantially the second and third year. Furthermore, the green manure crops themselves often provide additional food or feed. The farmer can sometimes slightly delay planting some cover crops so that they continue to grow during the dry season when the land is ordinarily idle.

How to Choose a Good Green Manure Crop

Look for as many as possible of the following characteristics:

- It should be a fast-growing legume that grows well in a poor soil, if possible without the addition of fertilizer.
- It should produce large amounts of green foliage—20 to 30 tons each year. The foliage should be low growing and should spread out to cover the soil.
- It should manufacture large amounts of nitrogen (100 to 200 kilograms per hectare per growing season).

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- It should germinate readily and be easy to plant with little soil preparation (can be dibbled into the soil or broadcast over it).
- It should do well with the food crops to be grown with it.
- It should not be highly susceptible to plant diseases or insects.
- The grain crop grown in the same soil the following year should show a sizably larger yield.
- It should produce a crop that provides feed, food, or cash income.
- It should be drought resistant if it is to be planted late in the rainy season and will grow partly in the dry season.
- It should be shade tolerant if it is to be planted early and grown with tall-growing plants or plants with wide-spreading branches.
- Seeds or plants of the chosen variety should be readily available in quantity. Hopefully, some good alternate varieties are also available, so the farmer can plant more than one kind together.
- The combination of a grain crop and a green manure cover crop should control soil erosion, increase water infiltration, and maximize grain yields (assuming contour ditching and other recommended conservation practices are followed).

Note: You may not be able to find a legume with all of these advantages. The choice will depend on the seed supply and the farmer's priorities and needs.

How to Locate Suitable Species of Green Manure Cover Crops

1. Begin by looking at Table 3-1, a list of suitable green manure cover crops. (Check Appendix B for sources of seed.)
2. Discuss these crops with successful farmers in the area, and with local government specialists, private voluntary organizations, your program officer, and senior PCVs.
3. Look for a successful legume plant growing locally. You may find a good local bean already being used for food.
4. Refer to the following links: <http://www.echocommunity.org/?LegumeCoverCrops> and <http://www.sare.org/Learning-Center/Topic-Rooms/Cover-Crop-Topic-Room>. Both can provide information about how cover crops are used and the multiple benefits they provide. Because goals of particular farmers vary, as do local environmental constraints and opportunities, choosing an appropriate cover crop will be highly situational.

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Table 3-1. List of Green Manure Cover

Name	Main Use	Drought Resistance	Human Consumption	Fodder Value	Comment
Mucuna pruriens (velvet bean)	As green manure/cover crop to suppress weeds, add fertility, and control erosion.	Often used to protect the soil through the wet monsoon season	Medium, prefer distributed rains	Same As refried beans, in tortillas, and as coffee substitute.	Cows, goats, pigs and rabbits eat it well
Lablab purpureus (lablab bean) Dolichos lablab (lablab bean)	Cover crop, green manure	Highly resistant; grows during dry season	Seeds can be eaten green (like garden peas) or dry (like dry beans)	Animals prefer it over other species	
Vigna unguicular a (cowpea)	Cover crop, green manure	Highly resistant; some varieties produce fast	Green pods and dry seeds	Eaten by some animals	
Cajanos Cajan (pigeon pea)	Leaves can be used as green manure	Highly resistant	Dry seeds	Animals eat leaves and tender parts	
Vigna aconitifolia (moth bean)	Food and hay; cover crop	Extremely so; forms mat on soil surface	Yes—bean is excellent food. Dry seeds.	Good hay	Commerical crop in dry areas of India. Shades soil. Grows as mat on soil surface. Plant as second crop or with other food crop. Needs considerable moisture to establish. Once established, is deep-rooted and drought resistant.

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Name	Main Use	Drought Resistance	Human Consumption	Fodder Value	Comment
Canavalia ensiformis (jack bean)	Cover crop, green manure	Highly resistant	Tender pods; white dry seeds	Cattle eat it but prefer other species. Is preferred where dry season is a problem	Grows at 14C to 27C. Rainfall 4200 to 700 mm. Prefers full sunlight but tolerates shade. Altitude: sea level to 1800 M Soil: pH 4.3 to 6.8. Yields: Green weight 30 to 50 T/Ha.
Canavalia gladiata (sword bean)	Excellent green manure cover; for age	Yes	Young leaves and green pods, but mature beans boil and can be eaten if cooking water changed 2 or 3 times.	Same as Jack bean (see above)	As with Jack bean, grows under wide range of conditions. Soil pH 4.3 to 6.8 Does best in sunshine, tolerates shade, does well in lowland infertile soils. Tolerates waterlogging, salinity, and some frost. Altitude from sea level to 1800 meters.
Phaseolus lunatus (tropical lima bean)	Food. Also excellent as a green manure cover crop in hot humid lowlands. Not for low pH soils	More research needed; once established, resistant to drought	Dry white beans OK. Dry colored beans need very special cooking, changing water once or twice. Toxic if bitter taste. Young pods and leaves OK.	Probably good, since leaves and pods are eaten by humans	Well adapted to lowland usually tropics, especially highly leached infertile soils. Very high yields in lowland tropical rain forest. CIAT in Colombia is growing it with maize. Yield: 1 to 2 tons beans 5 tons corn. Seed pods non-shattering. Altitude: sea level to 2400 M. Prefers pH 6 to 7

Source: Compiled from World Neighbors and National Resources Council. 2002. *Tropical Legumes: Resources for the Future* (National Academy of Sciences). p. 1-108.

How to Plant and Grow Green Manure Cover Crops

1. Plant a green manure cover crop between rows of crops such as maize or sorghum. Follow the planting, growing, and harvesting practices recommended for each crop.
2. Since green manure crops are legumes, inoculate the seed with Rhizobia if the plant or similar plants have not been grown in the field recently. See directions in Appendix A.
3. Ensure that crops grown in combination are mutually compatible and beneficial. For instance, a green manure crop grown under partially shaded conditions should not require full sun.
4. At the next planting date, cut back the dead foliage and plant corn, dibbling it through the dead bean leaf-stalk mulch with a dibble stick or hand planter. Under this system, corn yields increase rapidly during the second year.

Case Study of Velvet Bean

An outstanding example of a successful green manure-legume combination is the velvet bean grown as a green manure cover crop in combination with corn. Workers for the Peace Corps and for World Neighbors in Honduras and some other parts of Latin America give enthusiastic reports on the velvet bean. It is well adapted to the region, fast growing, high yielding in nitrogen, and abundant in foliage. The farmer can leave the foliage in place to become mulch and compost. Many farmers who are using the velvet bean cover crop system now produce 2.5 to 3 tons per hectare of maize grain without buying any nitrogen fertilizer. In addition, they usually produce much more by adding commercial fertilizer.

How to Utilize Green Manure Cover Crops

Some farmers often plow this growth under before the next planting time. Although this somewhat exposes the soil to rainfall splash, it speeds up the breakdown of the material into organic matter.

Many other farmers cut down the dead stems and leaves before food crop planting time, leaving them on the surface without tilling the soil. This provides an excellent protective carpet. They then plant seeds or seedling through the carpet. This is an efficient conservation tillage technique.

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Compost

Compost is a mixture of green and/or dry plant materials, manure and some topsoil, miscellaneous organic materials such as vegetable peelings, and even a little commercial fertilizer (if available), to which some water is added. Soil microbes convert this within one to four months into a very good organic fertilizer—one that the farmer can produce right in his field or at his own homestead.

Composting refers to the process of decomposing organic materials into a soil-like material, which is known as compost. The process of composting can be managed by people so it happens quickly and results in a high quality soil amendment that will improve the productive capacity of the soil.

There are a number of ways to make compost. One follows in the box below, but there are links to others in the Resources section.

How to Make Compost

1. Obtain source of plant material, manure, topsoil, water, a knife, a spade, a bucket, wood, and nails.
2. Construct a wooden frame using wood and nails about 25 to 30 centimeters high to enclose an area of 1 to 2 square meters. This frame is the mold or form in which the compost is compacted. As the stack of compost gets higher, the frame will be moved higher.
3. Place the frame in the sunlight and near the garden or field where it will be used. Some farmers locate it near the animals that produce the manure.
4. Gather and stockpile the following materials: crop leaves and stalks, other dry leaves, green leaves from trees and shrubs, straw, grass, legume residues, and kitchen peelings. You will need about 1,500 pounds of plant materials to make a cubic meter of finished compost. Chop the plant materials into relatively small pieces (about 5 to 8 centimeters long) so that they will decompose quickly.
5. Collect about 500 to 700 pounds of manure for each cubic meter of composted materials. Be sure there is plenty of water and some topsoil you can use.
6. Loosen up the ground before starting the pile. This will improve the drainage. Pile 25 to 35 centimeters of plant material in a layer on the ground inside the frame. Take out anything that will not decompose, such as rocks, glass bits, or plastic. Compact the mixture by continually walking on it.

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7. Add water evenly over the plant material layer. You will need 20 to 30 liters of water for green plant material, but more for dry plant material (about 40 to 50 liters). The layer should be thoroughly damp, but not too wet—too much water will drown the bacteria and too little will slow down decomposition. The layer should feel well moistened, like a wrung out cloth.
8. Cover the first layer with a layer of manure 6 centimeters to 8 centimeters thick.
9. Water evenly with another 12 liters of water per square meter, or more for dry manure.
10. Insert 12- to 18-centimeter diameter poles upright in the pile, one in each square meter (more or less). Place the narrower end of the pole at the bottom so that it will come out more easily. In four or five days, you will pull the poles out. The long holes left vertical in the compost pile become air vents for oxygen and carbon dioxide to exchange, thus improving aeration.
11. Continue adding alternative layers as described above—a layer of plant material and water, then one of manure and water, and then repeat. Raise the frame as the stack grows taller. The stack should reach a height of 1–1.5 or more meters. If the stack is too high, some layers may fall off the pile. With each layer, insert the posts, and then remove them after four or five days.
12. Top off the stack with about 3 centimeters of good topsoil. Cover the compost pile with straw, plastic, etc. to protect it.
13. Do not disturb the pile for about 30 days. During this time, much heat will be generated in the stack. Therefore, after 25 to 30 days, thoroughly mix the stack and add more water if it feels dry. Reassemble and repack it; reinsert the poles, again removing them after three or four days.
14. Thirty days after this mixing, mix the pile again and reassemble as in Step 1. This will be about 50 to 60 days from the beginning.
15. About three or four weeks after the final mixing (90 days from the beginning), the compost is a rich, organic matter-humus complex and it is ready to use.
16. Place the compost in the field near where you will work it into the planting bed or the narrow tilled row. Mix thoroughly with the soil in the row.

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Figure 3-5. Compost Being Made in a Frame

Photo c/o creativecommons.org



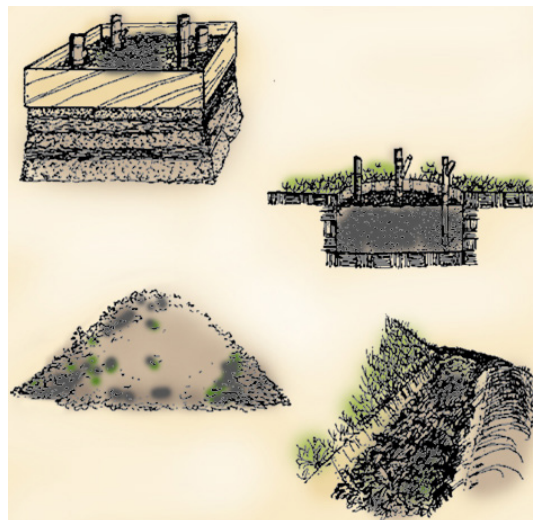
Types of Compost Piles

Composts can be placed in a conical stack on the ground, like a small haystack. They also can be below ground, which may be preferable in areas where water is scarce or where the humidity is low and temperatures are high.

The compost may or may not be turned. If left undisturbed, it takes one or two extra months to finish curing. Then the farmer adds more soil to the compost before planting in the trench. This rectangular underground pit works well in arid regions where water is scarce and the evaporation rate is high.

Composts can be dug in a trench or ditch on the contour in the field. This compost would not be turned or mixed, but takes much longer to be ready to use (about five to six months). Soil is then mixed in and the crop planted into the same trench.

Figure 3-6. Types of Compost Piles (clockwise from left: above ground, underground, volcano compost pile, and contour compost ditch)



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Table 3-2. A Comparison of Composting and Green Manure Cover Cropping

	Compost	Green Manure Cover Crop
Action	Merely decomposes organic matter a farmer already has on the farm.	Can add over 30 tons of additional organic matter per hectare to a farmer's system. This is important because organic matter is often in short supply on small farms or is already being recycled.
Nutrients	At best, will return to a farmer's field about 98 percent of the nitrogen that it started out with.	Will add 100 to 200 or more kilograms per hectare per year of nitrogen to the system.
Labor	Takes a tremendous amount of work as anyone who has made compost can attest to. In fact, in most developing world countries, it is difficult to make enough for basic grain crop. It will often do well in a vegetable garden, but it is difficult to make enough compost for good yields of field crops like corn and millet.	Takes some labor to plant (using a dibble stick), but nowhere close to the amount of labor needed to make a compost heap. In some cases, where the cover crop is intercropped among traditional crops (like corn, sorghum, or millet), it covers the ground so well that one or two weeding operations can be eliminated, thereby reducing the net increase in labor to nothing.
Food	Cannot be used as a food source for either animals or humans.	Can be a valuable food source for both human and animal consumption.
Production	Cannot be produced in enough quantity to sell. The farmer will need all he or she can make for his/her own garden, plus some for his/her field crops.	Often can produce enough seed so the farmer can sell some for cash.
Soil protection	Usually is placed around the hill or in the row and worked into the soil. It usually does not form a carpet over the soil surface to protect it from raindrop splash erosion.	Once established, forms a leafy cover over the surface that catches the large raindrops before they hit the soil. It serves as excellent protection. It also increases rainwater infiltration into the soil.

Source: Extracted from World Neighbors in Action Newsletter, Vol. 19, No. 2E. 2014.

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Summary of How to Increase Soil Fertility

If soil-testing laboratories are available, use the tests and follow the following recommendations:

- Compost. Use all available manures and composts possible.
- Grow green manure crops. Grow green manure cover crops that are adapted and produce 100–200 kilograms of nitrogen per hectare and 20–30 tons per hectare of green material.
- Mulch. Use crop residues as mulch or turn them under.
- Fertilize. Use recommended amounts of commercial fertilizer.
- Use an appropriate soil and water conservation program so that erosion is no more than 11 tons per hectare per year.
- Use intercropping. Even if the farmer does not use green manure crops, he or she can use food crops in ways that cover the soil as much as possible. Intercropping with well-chosen combinations can help achieve this. Even a partial cover significantly reduces soil erosion. Important: Where possible, intercropping with a green manure crops is always best.
- Plant together different food crops of different heights and growing habits. If plants are harvested at different times during the growing season, the crops may provide longer partial soil cover than if the crops are harvested on the same date. Grow such combinations of food crops together where: (1) the leaves of the crop combinations overlap to form a low umbrella over the soil surface, (2) the crops sprout up and leaf out quickly, and (3) the two crops are compatible. You and the farmers may want to consider better combinations for their particular location, rainfall, and elevation, as well as marketing potentials for various crops.
- Make a rainfall calendar and apply it. With the help of farmers and PCV friends, do your best to fit this to local recommended planting and harvesting dates for different crops. Learn the best planting dates so that maximum growth for cover occurs before the peak rainfall storm intensity comes. Combine your rainfall calendar and your crop management calendar. Farmers will often be eager to help you plan. (Refer back to Chapter 1 for directions.)

Ch 4: Changing the Landscape to Conserve Water and Soil

Introduction

The slower the runoff water flows, the less soil it will transport. As the water flows more slowly, there is more time for more water to soak into the soil. Slow-flowing water also allows more particles of soil to settle out and be deposited on the farmer's field, rather than on the bottom of a river. As runoff water flows more slowly, erosion diminishes.

This chapter will help you recognize types of changes to land surface for conserving water and soil, specifically diversion drainage ditches, contour drainage ditches, contour barriers, and bench terrace.

Types of Changes to Land Surface for Conserving Water and Soil

Diversion Drainage Ditches

Farmers can construct diversion drainage ditches to divert excess water away from their fields (water coming from neighbors' fields above or from a higher elevation elsewhere on their own farm). These ditches should empty into a control drainage ditch, which runs down the hill to exit at the bottom of the hill without erosion occurring.

Contour Drainage Ditches

Farmers can also use contour ditches to catch the water and to hold it or release it slowly. By doing this, they trap the runoff water and retain the suspended sediment, thus decreasing erosion. In addition, contour ditches spaced at intervals across the field shorten the length of slope.

Exit Drainage Ditches

The drainage water must empty some place. Sometimes the farmer can find a natural place for the water to empty into, perhaps a small creek or natural gully, perhaps some grass-covered pasture. If not, he or she will need to dig a protected main control drainage ditch that goes down the hillside, usually at the edge of the field.

When the water in the exit control drainage ditch reaches the bottom of the farmer's field, it should discharge into a farm pond, or lead to a natural gulf or stream. If this is not feasible, the farmer should consult with neighbors and work out cooperative arrangements to share ditches.

Be sure the drainage water does not flood a neighbor's property.

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Contour Barriers

Farmers can build contour barriers to restrict the rate of the water flow. Barriers reduce the length of slope. Eventually, as sediment accumulates along the upper side of the barrier, the percent of slope also lessens.

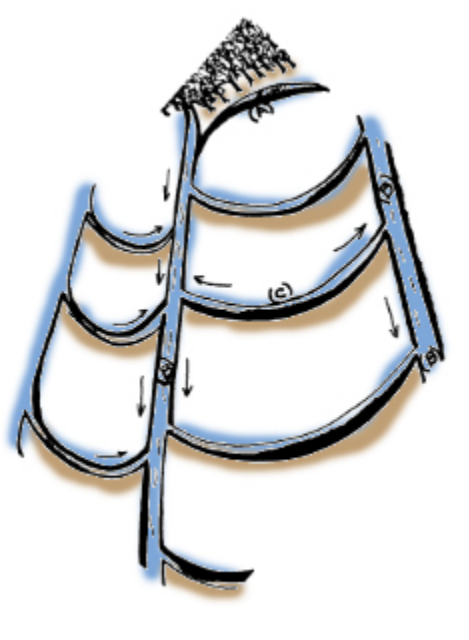
Bench Terraces

Farmers can build bench terraces that change both steepness and length of the slope.

In all cases, for any kind of ditches or terraces, a key principle must always be to build them so that the water does not collect during heavy rainstorms and spill over the edges. Water washing over the lip or edge of the terrace or contour ditch can quickly form gullies all the way to the bottom of the hillside. This can cause serious damage and loss to the system, which has been built at the cost of many days of backbreaking physical labor.

Figure 4-1. Small Farm Drainage Control System with Diversion Control Ditch at Top

Modified from World Neighbors



Note: Control ditch (A) empties into the exit control drainage ditches (B). The supplementary contour ditches (C) catch excess water in the field. They empty also into the main control ditches (B), which carry all of the excess water away from the farm.

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At the top of the hill, this ditch can be 50 to 60 centimeters deep and 50 to 60 centimeters wide. It should be deeper and wider as it goes down the hill, possibly 75 centimeters or even 1 meter deep and wide near the very bottom of the field (assuming the size of the field is about a hectare). The ditch collects and handles a lot more water as it approaches the bottom of the field.

Diversion Drainage Ditches

The first step in controlling excess water on a field is to catch and divert runoff water from hills or fields above or from the side. Build a diversion ditch at the top of the field (and around the sides of the field, if needed, to keep other floodwaters away). The diversion ditch is a drainage control ditch.

The diversion ditch must be wide enough and deep enough to handle even the heaviest storms without overflowing.

The farmer digs the ditch on the contour across the uppermost part of a field. It should be at least 50 to 60 centimeters deep and 50 to 60 centimeters wide, with a 1-percent slope (grade) in the direction of the outlet.

If excessive water falls in the heaviest rainstorms, the ditch can be made wider and deeper to handle the surplus water from the next large storm.

Important: Drainage control ditches should empty into an “exit control drainage ditch.”

Water flowing down steep hillsides in a gully or ditch builds up a lot of cutting (hydraulic) force, which can quickly deepen and widen the ditch, eroding good soil. The speed of running water in the exit drainage ditch must be controlled.

One excellent water-slowng technique is to build check dams within the drainage ditches. Check dams are small barriers or dams to “check” the water before it continues down the drainage ditch.

With all forms of check dams, take special care that they hinder, but do not stop, the flow of the water. Stopping it altogether will cause flooding over the bank of the ditch.

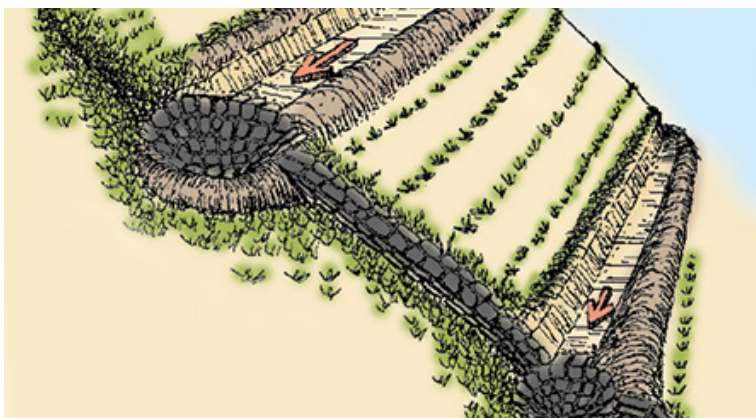
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How to Build a Check Dam

1. Line the bottom and sides of the ditch with rocks. Rock-lined ditches are excellent. The rocks must be large enough not to be moved by the force of the water. Observe the size of rocks used on roadside ditches or other farms.
2. Make check dams with rocks or concrete. The top rim of the check dam should be lower than the top of the ditch bank, so that at peak flood the water will not spill over the bank of the ditch to run wild. When rocks are not available, build check dams from tree limbs and poles. Drive posts or tree limbs into the ground to hold the structure in place and interweave small limbs, bamboo, vines, etc., through them. Stakes taken from a fast-growing legume tree that sprouts easily will grow to form an excellent barrier. Prune the trees as needed.
3. Line the drainage ditch by planting strong, deep-rooted short grasses. This living lining for the bottom and side of the ditch works well if the hills are not too steep. Water flows over the short grass, flattening it down to overlap the grass immediately below it. This acts as a thatched grass roof over the soil to prevent erosion in the ditch.
4. Build the ditch so that the water inside it falls at intervals over steps (vertical drops) and lands in rock basins or log catchments, which break the fall and prevent gouging of the soil. In a cross-section view, this looks like a series of small waterfalls separated by slightly sloping (1 percent) streambeds, with each waterfall dropping vertically into a catchment basin. When the land is steep, the vertical drops in the ditch change the percent slope and also the length of slope of the ditch. The water will flow slowly over the 1-percent slope between the mini-waterfalls and catchment basins, if they are properly spaced.

Take two precautions with this system: (1) line the catchment basin floor well with protective cover (rocks, limbs, logs); and (2) protect with stones or wood the lip and wall of the ditch over which the water will spill vertically.

Figure 4-2. Rock-lined Drainage Control Ditch



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Figure 4-3. Check Dams Made from Rocks or Tree Limbs and Vine



Note: The dam wall should rise above the ditch bank. It should be a little below the top of the bank. Otherwise, water will flood over onto the adjacent land.

Contour Drainage Ditches

Sometimes excess runoff water accumulates farther down the hillside. The farmer can dig one or two auxiliary contour drainage ditches at a gentle 1-percent slope to the exit control drainage ditch.

The main purpose of these ditches is to serve as barriers and catchments for water and sediment, in lieu of diverting runoff water. Therefore, the farmer usually constructs and locates them differently.

How to Construct Contour Ditches

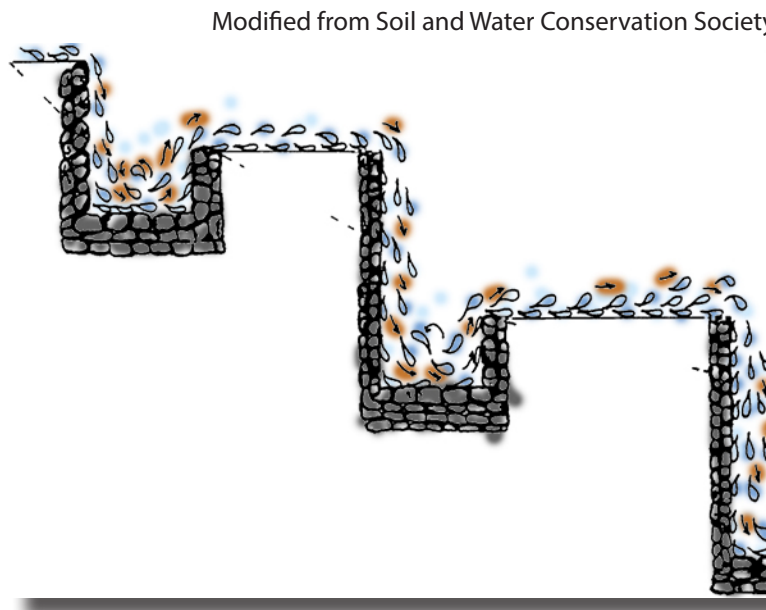
1. For de-nourished soils with good infiltration rates, construct contour ditches with a zero slope to act as a barrier to water runoff. Build the ditches so they hold all the water and soil particles they catch. The water soaks into the soil; the soil particles stay in the ditch. A zero slope is feasible only if the soil is deep enough and can soak up the water fast enough to hold and store all of the rainfall and soil sediment.
2. Even though the ditches are level, they should open into an exit control drainage ditch. In heavy peak storms, excess water will then run out of the end of the ditches to spill into side drainage ditches, rather than overrunning the banks of the contour ditches. Remember that small, low check dams can be placed in the contour ditches if the water tends to prematurely run out of them into the exit control ditch.

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3. Although its main purpose is to serve as a barrier, the contour ditch for shallow soils with limited storage capacity, or for heavy soils with low infiltration rate, must have a 1-percent slope (grade) and must empty into an exit drainage control ditch. Otherwise, excess accumulated water will spill over and run uncontrolled down the hill. The farmer with shallow soil may choose to use contour ditches as an interim measure while living barriers are being established. (Check a discussion of living barriers later in this chapter.)
4. On moderately sloping land, the farmer spaces the ditches 5 to 6 meters apart. On steeply sloping land, the farmer spaces them 3 to 4 meters apart. The steeper the land, the closer together the contour ditches are placed. They should be 40 to 50 centimeters deep and 50 centimeters wide. The depth and width remain the same.
5. When digging the ditch, the farmer piles the soil on the lower bank of the ditch to form a dike. This will help keep water in the ditch from spilling over during heavy rains.
6. On the other hand, if the farmer wishes to plant a grass barrier in addition to the ditch, he or she should throw the soil from the ditch on the upper bank to help form a dike and should then transplant grass slips onto that dike.

Caution: Contour ditches must be kept clean. They should be cleaned once or twice a year, or more often if needed. Otherwise, they will gradually fill in.

Figure 4-4. Vertical Drop Check Dams Made from Rocks (Vertical Cross-section View)



Note: The steeper the slope of the field, the shorter the distance between the structures becomes. Between the drop check dams, the water flows fairly slowly and does not erode the ditch side.

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Table 4-1. Advantages and Disadvantages of Contour Ditches

Advantages	Disadvantages
<ul style="list-style-type: none">• Retain and conserve soil and water and effectively work to prevent erosion.• Catch and hold all runoff water and soil particles.• Act as an excellent first step in a more complete erosion control system, which the farmer can develop over time.• Are relatively simple and quick to construct.• Help increase crop yields if used together with adequate organic and commercial fertilizers.• Can later be converted into living barriers.	<ul style="list-style-type: none">• Do not work efficiently on very shallow or heavy clay soils, except as slow drainage ditches.• Must be kept clean or they will fill with silt and cease to function.• Must be maintained from time to time to keep them vertical.

Figure 4-5. Contour Ditches to Catch and Hold Water and Sediment

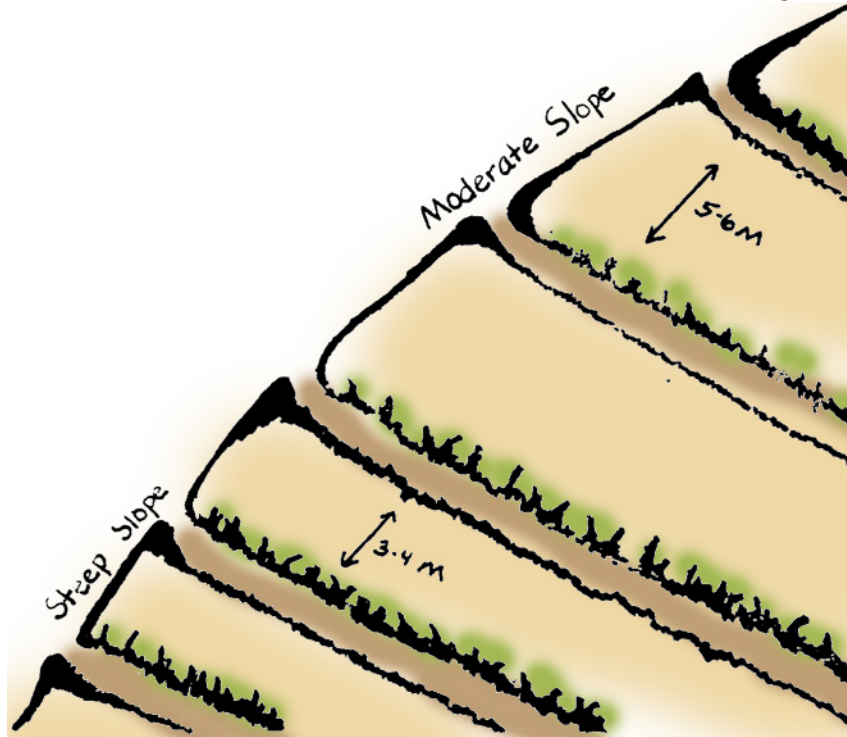


Note: These contour ditches are effective in conserving rainwater when the soil has a good infiltration rate. The field trash and mulch are left as protection on the slope.

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Figure 4-6. Spacing Contour Catchment Ditches in Order to be Effective

Modified from World Neighbors



Note: Contour ditches must be closer together as the slope of the field increases because the rainwater runs into them much faster on steep slopes than on moderate ones.

Contour Barriers

Contour barriers are live or dead materials placed on contour lines in a field to check the fast flow of water down the hillside. They very effectively stop, or slow down and spread, the runoff water so that most of the soil particles are deposited there.

Since slower flow allows more soil particles to settle out, sediment from the runoff water will accumulate on the uphill side of the contour barrier. Silt, organic matter, and clay sediment will gradually build up at their base. Gradually, a bench terrace with a relatively flat surface of better soil will form—an important long-term benefit.

Dead barriers are made from inert objects, such as rocks, logs, and limbs. Farmers even pile up soil in earthen mounds. Live barriers are made from living plants grown to form an obstruction. Whether dead or live, the barriers should be placed on contour lines.

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Figure 4-7. Contour Rows

Photo c/o creativecommons.org



Note: Contour tillage on moderate slopes where soils have good infiltration rates are effective conservation practices. Note the raised banks, which serve as emergency protection in case of excessive flood.

Dead Barriers

Most dead barriers are constructed from rocks or earthen mound. However, when a forest is cleared, farmers often use logs and limbs. In humid climates, most logs decay rapidly. When this happens, the farmer can dig a contour ditch above the decaying logs, throwing soil on top of the logs and planting grass or legume trees to convert the space into a living barrier.

Figure 4-8. Erosion Control - Dead Barriers Made of Tree Logs

Photo c/o creativecommons.org



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Earth Banks

Farmers often pile mounds of earth to form dikes or banks along a contour line. These work well in many places to catch and hold all the water (with a planned emergency overflow outlet into a controlled drainage ditch to handle heavy, long duration rainfall).

One such type is called Fanya juu (meaning “throw the soil up” in Kiswahili). In this method, the farmer digs a contour ditch and throws the soil above the ditch, then plants grass on this soil. Each year as the ditch is cleaned out, the farmer throws the silt from the ditch back onto the top of the grass mound. Year after year, he or she repeats the procedure and maintains the grass cover. Eventually, when enough soil has been thrown onto the mound, and enough eroded soil from above has been deposited, a bench-like floor forms. The farmer can easily finish it into a regular bench terrace.¹

Solid Rock Walls

Where rocks are available, rock walls are common and can serve as an excellent barrier. Usually rock walls are loosely constructed, with spaces for water to seep through very slowly. However, some farmers fit rocks tightly together into solid walls, sometimes using cement to hold the rocks together. Solid rock walls are much more common in more arid areas. With low rainfall, they often can catch and hold on the field most or all of the rainwater.

¹ To learn more, see <http://www.iied.org/sustainable-land-management-technologies>.

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Table 4-2. Advantages and Disadvantages of Solid Rock Walls

Advantages	Disadvantages
<ul style="list-style-type: none">• Removing the rocks from the field improves the land• Rocks are sturdy.• Rock walls are relatively permanent.• Crops can be grown up against both sides of either loose or solid rock wall. In fact, next to the wall, on the up-hill side, is a choice spot to grow vegetables. The soil is especially moist and fertile at that location, where the water deposits sediment and nutrients most frequently.• Farmers often grow pineapple in this location. Vine crops grown near the wall can be trained to grow over and along it.• They retain all the water and the soil particles.• The buildup of deposited soil after storms will be much faster than with less solid barriers. Less time will be required to form a bench terrace.• Solid rock walls, once in place, are quite permanent and easy to maintain. They should not need much attention for some time.• They are less vulnerable to damage from animals.	<ul style="list-style-type: none">• A solid stone wall needs more accurate engineering than a loose stone wall if it is to hold all the rainfall. Careful calculations and design must ensure that the wall is strong enough and tall enough to withstand heavy rainstorms. Spillways must be designed for excess water from unusually heavy rains.• Building solid rock walls calls for supervision by a mason or skilled craftsman. The rocks require careful fitting together.• Solid rock walls are more expensive and slower to build than loosely fitted walls and require semi-skilled labor.• The designer of the wall must know the soil depth and infiltration rate of the soil, as well as peak amounts of rainfall.

Loose Rock Walls

Figure 4-9. A Loose Rock Wall Barrier



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Table 4-3. Advantages and Disadvantages of Loose Rock Walls

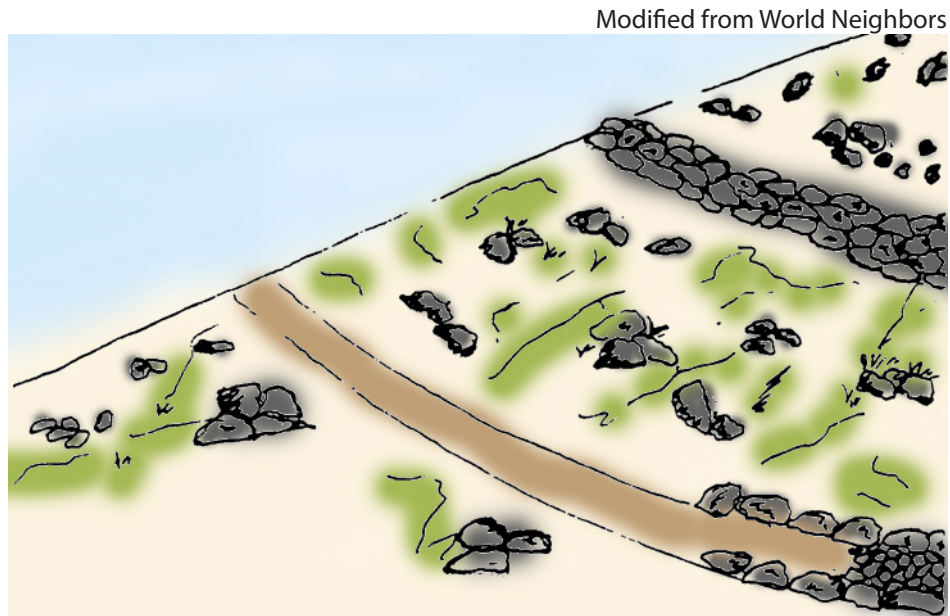
Advantages	Disadvantages
<ul style="list-style-type: none">• Loose stone walls are relatively inexpensive to build if plentiful rocks are in the field.• They do not require the careful engineering and precise construction of solid rock wall, yet they work well.• With time they will still form a terrace if rocks are fitted as closely as possible.• These walls are easy to maintain if livestock are kept out.• As with solid rock walls, stones removed from the field leave more room in the soil for plants to grow.	<ul style="list-style-type: none">• Many farmers who would like to put up rock barriers do not have enough rock. In these cases they might use a combination of rocks and earth covered with grass, or rocks stacked along the contour line plus a live barrier of legume trees planted next to their downhill side.• Loose rock walls are susceptible to damage from grazing animals or playing children. Cattle or goats wandering unsupervised in a field can destroy the effectiveness of the wall. If rocks are missing from a spot in the wall, water can rush through and begin to cut a gully below. Fencing or vigilance is important.

How to Construct a Loose Rock Barrier

1. Lay out the topmost contour line; clear a pathway on it.
2. Make a contour (level) bed 50 to 60 centimeters wide and about 10 centimeters deep, following along the entire contour.
3. Choose rocks that fit together as well as possible.
4. Separate larger rocks and smaller ones into two piles.
5. Place the larger rocks on the outside edges of the wall. Use the smaller stones to fill in the center space.
6. Continue until the wall reaches about 1 meter in height.
7. At a later date, the farmer might plant a row of legume trees, such as *Gliricidia*, on the lower side to reinforce the wall. Trim back to 1 or 1.5 meters when they are 18 months old. Keep them trimmed back from time to time, as needed, to keep root and shade competition with food crops to a minimum during the growing season.

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Figure 4-10. Building a Loose Rock Barrier on the Contour



Low Row Ridges and Row Beds

When used on very moderate slopes, row ridges and row beds can be effective in slowing down runoff water. They work well where farmers want to plant certain crops in raised ridges or beds. Farmers may like to pile up ridges on the contour to grow root crops (like yams). Alternatively, they may use raised ridges where soil drainage is poor to allow plant roots to have more airspace in the soil.

The raised barrier on the contour captures or slows down the water from most rains if it is on very moderate slopes. If the soil is shallow or has a low infiltration rate, excess water from the beds should flow into a drainage ditch.

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Table 4-4. Advantages and Disadvantages of Low Row Ridges and Row Beds

Advantages	Disadvantages
<ul style="list-style-type: none">• In poorly drained soils, raised beds or contour ridges allow better air exchange in the rooting area. Plant roots find more air space in the soil because excess water drains more quickly from the raised part of the bed.• Raised contour beds work extremely well when used for vegetables, which are planted closely together and need much hand labor.• The farmer can walk between the rows of crops. Thus, when cultivating, he or she does not compact the soil around the crops.• The farmer will do less painful stooping when weeding or doing other crop maintenance on raised beds or ridges.• Raised beds are a traditional farming method in West Africa. Wherever farmers already farm with raised beds, they just need to learn to put the beds on the contour to help conserve water and soil.	<ul style="list-style-type: none">• Small raised ridges or beds by themselves are not effective barriers on steel.• They should only be used on very moderate slopes.• They require much labor to build and maintain. They must be restructured every planting season.• The soil in raised beds will dry out more quickly than in regular beds, which is a problem to be watched with sandy soils or in low rainfall areas.

Live Barriers

Live barriers are living obstructions, perpendicular to the flow of water.

Most farmers in the tropics can grow some type of live barrier to impede water runoff. In fact, many tropical smallholders are already using this technique with great success.

Plants seeded or transplanted very closely together on contours across a field can form excellent barriers. They function very much like dead barriers and can be equally effective. Not only can live plants make effective barriers, but many varieties also contain much organic matter or organic nitrogen fertilizer or both.

The soil from cultivation and erosion, which accumulates above the barrier year after year, eventually becomes a bench terrace; the barrier of living plants then becomes the terrace wall or riser.

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How to Choose Suitable Live Barriers

- Choose the best type of live barrier for the particular slope, soil, and other farm conditions.
- Choose the plants best suited to local conditions and the farmer's need. Establishing live barriers requires considerable labor, cost, and land. Farmers will want to choose the types of plants carefully.
- Choose preferably two or more types of plants to form a dense, lasting, and durable barrier. If possible, they should provide a useful crop. They should grow well in that particular locale and in that particular soil.
- Encourage the use of legumes.
- You will find two general types of live barriers grown on the contour: those made of green manure, and those formed by legume trees or legume shrubs growing very closely together with intertwined root systems and trunk. Combining these two types makes the best and most effective living barriers for either steep or moderate slopes in humid regions. The farmer plants a double row of trees (especially leguminous trees) on the top of the dike of a contour ditch. He or she also plants on the sides of the dike to keep it from eroding.

Legume Trees and Shrubs

Trees and shrubs make a very strong barrier that can even help support rock walls and earth mounds, in addition to acting as very strong barriers by themselves. Many of them can withstand severe weather and recover for quick regrowth, and have a deep root system that withstands drought.

A number of legume trees and shrubs provide all these benefits, plus tremendous special benefits in increasing soil fertility. These trees can play a dual role: (1) as a living barrier; and (2) as a vital source of organic nitrogen fertilizer and green manure.

The fields of most tropical smallholders have infertile soils, which are usually very low in nitrogen and phosphorus. The hill farmer needs to use more legume trees in barriers because of their usefulness as green manure and extra organic nitrogen. Manure or commercial phosphate fertilizer may need to be added for healthy legume tree growth in some cases.

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Table 4-5. Advantages and Disadvantages of Legume Trees and Shrubs

Advantages	Disadvantages
<ul style="list-style-type: none">• They produce enough nitrogen fertilizer for their own needs. Some types of legume trees can produce 100 to 200 kilograms or more of fertilizer nitrogen per hectare per year.• The tree leaves, twigs, and stems are rich in protein nitrogen. When trimmed from the trees, they can be worked into the soil as green manure fertilizer or left on the surface as a mulch and fertilizer. Also, adding the leaves to compost can greatly improve its quality.• The depth of the tree root system allows it to capture and bring to the surface other plant nutrients, such as potassium, calcium, magnesium, etc., from the deeper rooting depth. The deep roots actually do some recycling of nutrients, which are beyond the rooting depth of field crops. Note: For recycling to be effective, the subsoil must have nutrients and a healthy environment for root growth.• Since tree roots go much deeper into the soil than food or feed crops, they can use moisture from greater depths to survive.• Some legume trees produce a high quality “cut and carry” feed for animals. If needed, extra trees for this purpose should be planted elsewhere to prevent the live barriers from being destroyed.• Some easily sprouting varieties that can be planted as stakes will sprout and root and can also be used as living fences or fence posts. Gliricidia is commonly used for this.• Larger pruned limbs can be used for firewood or converted to charcoal to sell.• Trees can produce pods and seeds for human food, animal feed, or sale. Seeds from a few mature trees can also provide seed stock for a small farm tree nursery.	<ul style="list-style-type: none">• Animals must be kept away or they will destroy the barriers. Damage of young trees by grazing animals can be a limiting factor. Protection of trees is a main concern.• Trees can be susceptible to diseases or insects.

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How to Protect Legume Trees from Diseases or Insects

- Plant two or more species together in living barriers to prevent catastrophe. One species may survive and produce better than another. Then, if one species dies out, the other will still provide a barrier and a crop to produce nitrogen fertilizer and organic matter.
- Before planting, inquire carefully about insects, diseases, and drought.
- Investigate and test all new varieties before recommending them. Some excellent plants for living barriers are Calliandra, Gliricidia, and Flemingia. For information on these varieties and others, see the tables at the end of the chapter.

Figure 4-11. Trees pruned back to hedges are excellent live barriers against erosion, if properly chosen, planted, and cared for. They also provide the farmer with extra dividend.

Photo c/o USDA NRCS



Figure 4-12. Most Live Barrier Trees are Multipurpose Trees. (Here, grass and legume trees help protect this highly erodible field.)

Photo c/o USDA NRCS



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How to Construct Live Barriers of Leguminous Trees

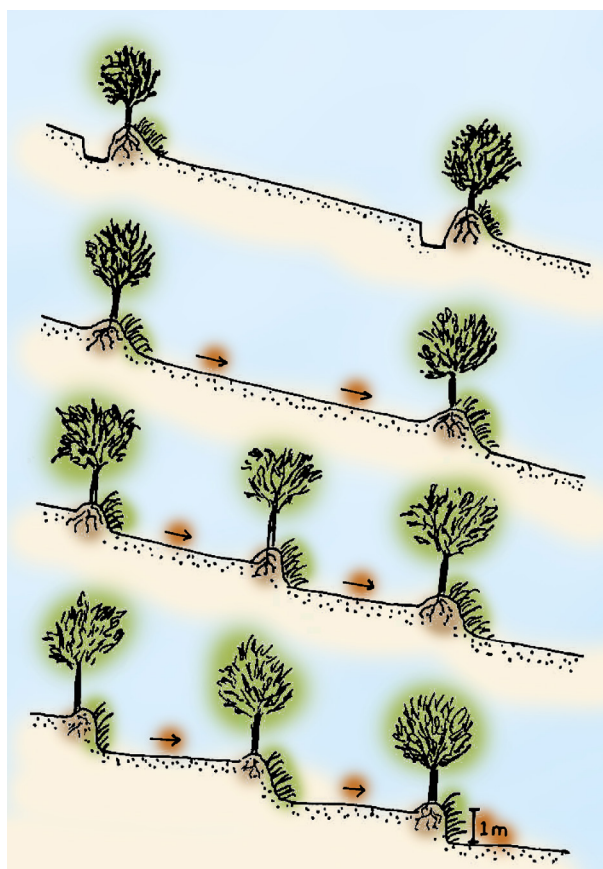
1. Before the rainy season, construct a contour diversion drainage ditch near the top boundary of the field, sloped 1 percent toward an exit ditch. Begin regular contour ditches 3 to 5 meters below the diversion ditch. The distance will vary according to the steepness of the slope. The steeper the slope, the closer together they should be. The ditches should measure about 50 centimeters wide and 40 centimeters deep. The ditches or barriers should be spaced about 1.5 meters apart in vertical elevation.
2. Pile the soil to form a dike or ridge along the lower or downhill edge of the contour ditch.
3. Early in the rainy season, plant the trees on the top of the ditch dike. Also plant or set out grasses on the sides of the dike.
4. Soak most seeds for 12 hours before planting. They will sprout more easily and come through the soil more quickly. In addition, any bad seed will float to the top. Some seeds require hot water treatment or chemical treatment before planting.
5. Treat the seeds with some soil taken from the area where the leguminous trees are already growing. (Rhizobium bacteria growing in association with the plant roots of legumes make nitrogen.) Rub the seeds in some of this soil just before planting. This transfers to the seed the special bacteria that make nitrogen. If this soil is not available, check locally to see where you can buy some of the bacteria mixture; or find an area where such trees are grown. You can also get help from the Nitrogen Fixing Tree Association in Hawaii, or other sources. The seed must be treated. If Rhizobium bacteria are not present, they cannot act to “fix” nitrogen.
6. Start planting at the beginning of the rainy season. Plant the tree seeds along the top of the dike on the down-slope side of the contour ditch. Plant the seeds so that roots and trunks of the trees closely wedge against each other as they grow. In order to get tight wedging or interweaving, plant two or three seeds together in a group, with the seed groups spaced 5 centimeters apart. Plant two parallel rows. In the second row, make a triangular shape with the plants in the first row.
7. Protect the dike on which the trees grow by planting grass under the trees. In erosive soils, plant grass slips on the lower side of the trees at the same time you plant the trees. If you wait until the next year, as some farmers do, much soil can wash away from the roots of the tree seedlings.
8. Plant grass slips on the side slopes of the dike, especially the lower side, in rows parallel to the tree rows. The grass will protect the sides of the dike from splash erosion. Close planting is desirable. The slips should be spaced 15 to 25 centimeters apart with 25

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centimeters between the rows, and you should again use a zigzag pattern. Spacing will depend on the nature of the grasses used. The grass will begin to grow in a few weeks and give some protection the first season.

9. Some people prefer to plant closely spaced pineapple on the lower side of the dike instead of grass. In either case, the sides of the dike, particularly the lower side, must be kept covered to avoid raindrop splash erosion.
10. At first, keep the contour ditch clear to channel the runoff water. After about two years, allow the ditch to fill. In time, the soil sediment from runoff will accumulate on the up-slope side of the trees, increasing the depth of soil on the bench top of the terrace. The land above the trees will become flatter and less prone to erode. It eventually will be a bench terrace.
11. Close planting is important. The farmer needs to grow a solid barrier, not only of the legume trees, but also of the protective grass cover. Combining legume hedgerows and rows of grass on the dike provides a desirable plant combination that should last a long time, efficiently curb erosion, produce good yields, and enrich the soil.

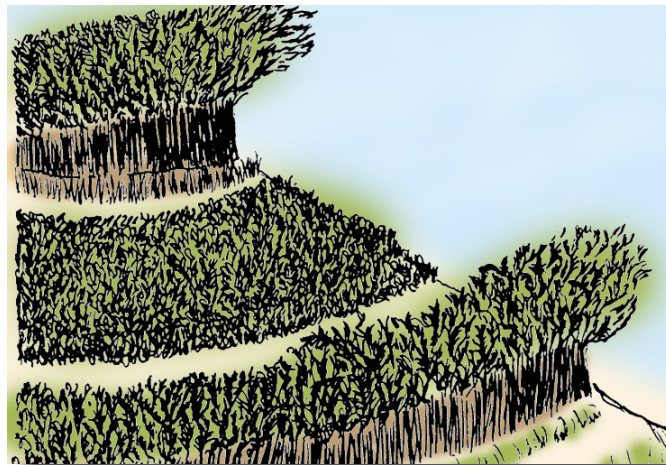
Figure 4-13. Cross-section View of Legume Tree Live Barriers



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Note: Notice the grass planted on lower side of dikes to protect from erosion. The tree seedlings are planted on top of a small dike protected by a drainage ditch, as shown. When the trees are well established, the ditch is allowed to fill with soil, which washes down. When the ditch is filled, the barrier stops most of the washing soil. Soon the slope of the field between the barriers begins to become flatter. Eventually, a level bench terrace is formed. If the first barriers are spaced too far apart, another one can be planted between them, as shown above.

Figure 4-14. Inter-planted Food Crops Growing between Two Rows of Nitrogen-fixing Legume Trees



Note: In part of the bottom row, the trees were pruned back to about 1 meter high. The rest of the trees need pruning. Notice the grass planted at the bottom of the trees to protect the lower edge from rainfall splash erosion around the tree trunks and roots.

How to Maintain Trees or Hedgerows

1. Let the legume trees grow for 12 to 18 months after planting before you prune them back. The first year, only cut them back to about 1.5 meter in height because the tree is still establishing its tap root and deeper root system.
2. The second year and succeeding years, prune the trees to 1 meter in height at food crop planting time. Trim the barrier as needed to prevent shade competition with the food crops.
3. Use the cut grass, tree leaves, and twigs for mulch, green manure, or “cut and carry” green feed. Hopefully the tree leaves can be left on the soil as a mulch and green manure fertilizer.
4. To the extent possible, let the trees grow without trimming during the dry season so that the roots continue to grow deep. Plant extra trees elsewhere if livestock feed is needed.
5. Protect both seedlings and mature shrubs and trees from grazing animals.

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Grass Barriers

Many grasses are useful as barriers due to their versatility and practicality. Farmers often use them in combination with other dead or live materials. On very steep slopes, grass barriers should not be used by themselves, but in combination with legume trees as described above.

If animals graze in the field during the dry season, the barrier should be a grass that they will not eat or destroy. The farmer needs to plant a tough, deep-rooted, unpalatable grass. The taste, odor, or spines and thorns on the plant leaf or stem surface may reduce palatability.

Figure 4-15. Unpalatable Grasses. Vetiver grass barriers do a good job of controlling soil erosion even though cows may be in the field during the dry season. They will not eat this unpalatable grass. Vetiver grass is easily transplanted, deep-rooted, drought resistant when well established, and unpalatable to both rodents and livestock.

Photo c/o creativecommons.org



Vetiver grass makes an efficient live barrier. It is widely used in India. Since it is unpalatable because of its chemical content, animals will not graze it. When well established and maintained, it holds back or slows down the runoff very well. It is very drought resistant and very deep-rooted, but does not spread into the field as a weed because it produces very few seeds and does not have stolons or rhizomes.

Vetiver grass grows in large clumps from a “spongy” rootstock with clusters about 0.5-1.5 meters high. The bundles can be uprooted and torn apart into small rooted slips for planting. The barrier will need two or three seasons to become well established, but it is very effective.

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How to Start a Vetiver Grass Barrier

1. At the beginning of the wet season, plant the slips about 15 centimeters apart.
2. Keep livestock away until the grass is well established and deep-rooted.

Palatable Grasses

Many palatable grasses serve both as good barriers and animal feed if the farmer confines the animals and carries the cut green feed to them. Check around for good local varieties. The palatability and nutrient value of the grass is important with cut-and-carry feeding.

By confining the animals, the farmer can not only grow a barrier, which he or she can use for feed, but also save the valuable manure to use directly as fertilizer or in compost.

Many varieties of grasses do well as both barrier and feed. Elephant grass is often an excellent choice. In some cases, sugar cane makes a useful temporary barrier. Often food crops such as pineapple combine very well with grass to form a barrier.

Table 4-6. Advantages and Disadvantages of Palatable Grasses

Advantages	Disadvantages
<ul style="list-style-type: none">• Grass barriers are usually easy to establish.• Grasses grow quickly and can be planted thickly.• Grasses are often easy to obtain. Local grasses are usually available as slips, sprouts, or joints to transplant.• Certain grasses are low-growing and/or form a mat, which make them suitable for covering mounds, terrace edges, ridges, and slow-flowing drainage ditches or waterways.• Where animals are confined, grass species can be planted as live barriers, which can provide animal feed to be cut and carried to the animals as green feed or dried as hay to be fed in the dry season. (Note: Grasses grow more abundantly when planted with a low-growing native legume.)	<ul style="list-style-type: none">• Takes time to establish• Many grasses prefer full sun so they won't do well in shade or partial shade• Very labor intensive to plant and establish• May be difficult to obtain planting material

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Bench Terraces

In bench terracing, the land is cut or reshaped into wide to narrow level steps or level tabletops going down the hill like stair steps. If the land is very steep, the tops will be narrow and look like benches. If the slope is not steep, the tops will be much wider and could appear more like tables than benches. Each individual tabletop or step extends some distance around the hill on the contour. In profile, the tops look like stair steps going down the hill. They are continuous, with one bench or one tabletop up against the other, just like stair steps.

The advantages and disadvantages of using continuous bench terraces are outlined below.

Table 4-7. Advantages and Disadvantages of Continuous Bench Terraces

Advantages	Disadvantages
<ul style="list-style-type: none">• Are suitable for growing any crop if soil is deep enough.• Can be used under a wide range of conditions.• Are suitable for any hillside, from a very minimal to a very steep slope if the soil depth is adequate.• Retain the maximum amount of soil and water on the bench top and in the soil profile.• Make possible the planting, cultivating, and harvesting of all field crops on a level platform.• Enable good crop growing practices.• Give maximum growing conditions and, with good management, lend themselves to high crop yields.• Are long lasting with proper maintenance.	<ul style="list-style-type: none">• Are very time-consuming and labor-intensive to build. Constructing continuous bench terraces on one hectare of land requires one man year or more of labor.• Are usually practical only for high value crops because they are very expensive.• Cannot be used on a very shallow soil.• Must be well designed and consistently maintained. Inadequate soil cover on the risers (the upper wall or bank side of the terrace), plugged up drainage systems, damage from grazing livestock, and similar oversights can lead to the loss of, or serious damage to, the system.• Require fencing out livestock and other protection from damage.• Do not prevent raindrop splash or the pounding of the soil surface into slurry. However, because the terrace floor is level there is no water runoff, or else it is controlled runoff (assuming a designed system). [Caution: if infiltration is slower than expected rainfall, the tabletop should be tilted inward and connected inward to a controlled exit drainage ditch.]• For maximum crop production, the soil on continuous bench terraces needs a green manure crop or compost. It will certainly need soil testing and recommended amounts of commercial fertilizers, if available. Maximum production is important because of the expense of installation.

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Figure 4-16. Bench Terraces

Photo c/o creativecommons.org



Following are different types of bench terraces, which are further described below:

- Standard bench terrace (continuous)
- Inward sloping bench terrace (continuous)
- Outward sloping bench terrace (continuous)
- Irrigation bench terrace (continuous)
- Intermittent bench terrace (discontinuous)
- Individual platform terrace (discontinuous)

Standard Bench Terrace (Continuous)

The standard bench terrace ideally has a 0-percent slope on the terrace itself (the bench top). The top is level as it extends around the hill on the contour. The terraces form a fairly unbroken pattern of steps down the hill. The bench surface may be relatively narrow or wide depending on the slope of the field, the soil depth, and the farmer's wishes. To protect the edge, the outside rim has a small raised lip about 10–15 centimeters or more high, which is covered with grass. The wall of the terrace (riser) should also be protected with grass cover or stones.

The terraces should be sloped 1 percent along the contour toward the exit control drainage ditch to permit slight drainage. The tabletop can also be slightly sloped inward if there is a danger of water spilling over the outside rim. Do not let water spill over the outside rim. This will dig a gully all the way down the hillside. If in doubt, use a 5-percent inverse slope on the tabletop.

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Standard bench terraces should be used on any field and any slope as long as the soil is deep enough.

The depth of the step down the vertical interval should not be more than two and one-half times the useable soil depth (the soil which will grow plants). Otherwise, you will expose rock or very poor soil when you cut down into the soil to build the terrace. Crops will not grow well there (if at all), leading to poor yields and erosion of the terrace.

Example: If the useable soil depth is only 30 centimeters, then the vertical drop of the bench terrace should only be 75 centimeters.

Inward Sloping Bench Terrace (Continuous)

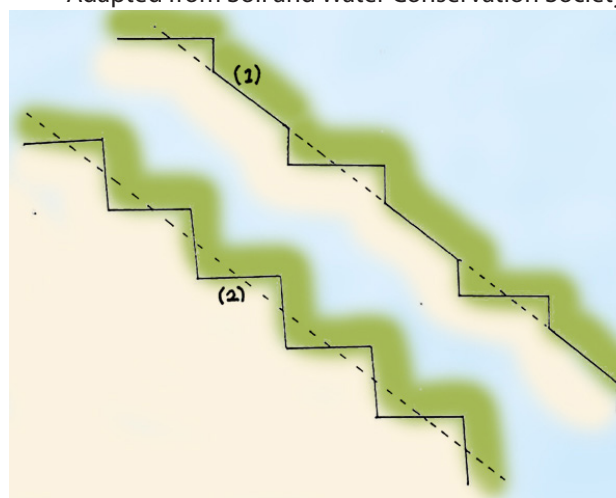
This terrace must defile the standard bench terrace by tilting the bench top surface inward, sloping it inward about 5 to 8 percent to allow for more water to be retained on the terrace top. An 8-percent inward slope is recommended if the soil is an easily eroded sandy/silty soil or if the soil has a low infiltration rate.

Outward Sloping Bench Terrace (Continuous)

With this type of terrace, the terrace bench top slopes outward (downward toward the outside edge) about 0.5 percent. This brings about improved drainage from the soil. Farmers use this technique in parts of Asia where the soil is heavy and shallow, or where landslides are common.

Figure 4-17. Sketch in Profile of Small Bench Terraces

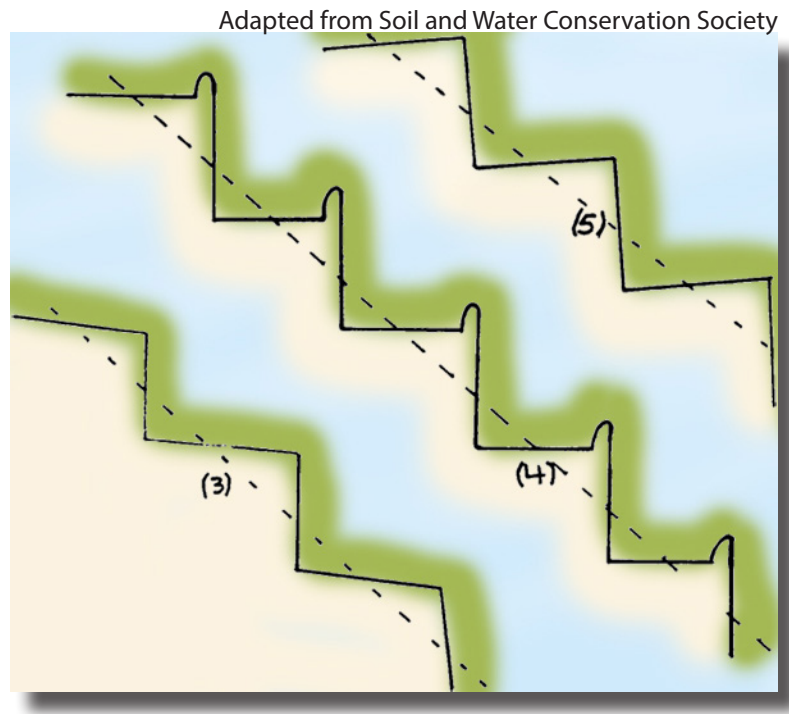
Adapted from Soil and Water Conservation Society



Note: Profile (1) on the right shows discontinuous terraces. The terraces have space between them, which maintains the original natural slope of the hills. Profile (2) on the left shows continuous terraces. Each terrace is connected with another terrace.

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Figure 4-18. Sketches in Profile of Other Small Bench Terraces



Note: These bench terraces are, from left: (3) continuous out-sloping terrace, (4) irrigation terrace, and (5) in-sloping or reverse sloping bench terrace.

In the latter case, the farmers want to keep excessive water from entering the soil and making it too slick internally, leading to a landslide.

Because the outward tilt can encourage erosion of the lip of the terrace, this system needs: (1) careful planting of grass along the lip and riser, (2) special contour drainage and discharge ditches, and (3) very accurate construction with the supervision of an engineer.

Irrigation Bench Terrace (Continuous)

These flat terraces have outer rims (walls) rising up 30 to 40 centimeters that permit the flat area to be flooded with adequate irrigation water. Low-growing grasses planted on the rims and side protects the outside rim (wall) from erosion. The farmer can apply irrigation water and can also control rainfall by interconnecting terraced plots and ditches. Rice paddies utilize this type of terrace.

Check with local, successful irrigation farmers for advice in constructing irrigation bench terraces, if a specialist is not available. In general, follow the directions for standard continuous bench terraces, but add sufficient height to the outside lip (edges) of the terrace to hold irrigation water and arrange for water level control.

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Intermittent Bench Terraces (Discontinuous)

Intermittent or discontinuous narrow bench terraces (also called orchard terraces) have strips of protective vegetative cover between them. In this system, the farmer alternates narrow bench terraces with undisturbed sloping soil. There is a terrace, then an undisturbed sloping strip, then another terrace followed by another strip, and so on down the slope. The undisturbed expanses must be completely covered with grass or other protective low-growing vegetation.

Intermittent bench terraces are ideal for tree and shrub crops like tea, coffee, and fruit trees. Therefore, farmers often use them in orchards in very hilly fields. They are sometimes called orchard terraces.

Figure 4-19. Close-up View of Bench Terraces on Moderately Sloping Hillside

Photo c/o USDA NRCS



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Figure 4-20. Terraced Rice Paddy

Photo c/o creativecommons.org



Table 4-8. Advantages and Disadvantages of Intermittent Bench Terraces

Advantages	Disadvantages
<ul style="list-style-type: none">• Require less labor than continuous bench• Allow the growth of useful products on the sloping land between terraces. grass-legume combination) on the intervening sloping land since land between the terraces is vulnerable to erosion.	<ul style="list-style-type: none">• Require good vegetative cover (e.g., terraces (although they are still labor intensive to construct), yet still provide convenient and productive level platforms at intervals.• Require maintenance—workers must keep the back wall (the riser) well covered with grass, maintain a healthy vegetative cover on areas between the terraces, and clean drainage ditches.• Require fencing or other protection from animals.

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Individual Platform Terraces (Discontinuous)

These are short lengths of individual terraces, each one having space for only one tree to grow. Oil palm plantations often use these. They can be used on very steep land—land too steep for conventional farming.

The platform bench terrace is quite vulnerable to erosion since it protrudes. The farmer should protect the whole area with standard contour drainage ditches spaced according to slope. Good ground cover should be planted over the whole area, including the protrusions mentioned above. This could be low-growing grass or shrub, or, even better, a low-growing grass-legume combination that grows well together. It should require little attention, produce its own nitrogen, and be able to compete with weeds.

Table 4-9. Advantages and Disadvantages of Individual Platform Terraces

Advantages	Disadvantages
<ul style="list-style-type: none">• Provide floors for growing individual trees.• Are excellent for large fruit or nut trees on steep slope. They permit the planting of a desirable crop on land, which might otherwise have limited value.• Enable planting, fertilizing, weeding, pruning, mulching, and harvesting of the trees more easily.• Help retain soil moisture and control erosion.• With grass-legume crops between platforms, provide animal feed as well as erosion protection.	<ul style="list-style-type: none">• Are not suitable for row crops, only for tree crops.• Need constant maintenance of drainage ditches.• Are highly susceptible to erosion. Vegetative cover must protect the soil on the platforms themselves and on all areas between.• Require protection from children and animals.• Require considerable labor to construct (though much less than continuous bench terraces).

2 More information on this ongoing work can be found on the World Agroforestry website: <http://worldagroforestry.org/newsroom/highlights/incorporating-trees-agriculture-outstanding-success-re-greening-sahel>, [http://worldagroforestry.org/newsroom/highlights/niger percentE2 percent80 percent99s-re-greening-revolution](http://worldagroforestry.org/newsroom/highlights/niger-percentE2-percent80-percent99s-re-greening-revolution), and the book *The Quiet Revolution: How Niger's farmers are re-greening the croplands of the Sahel*. <http://www.worldagroforestry.org/downloads/publications/PDFS/BL17569.PDF>

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Precautions when Constructing Bench Terraces

- Take special care in designing and building a bench terrace. You may not know the exact infiltration rate for the soil or the particular soil type. You will be dealing with many unknowns. You may not have accurate rainfall data: the total annual rainfall, the rainfall rates, and amount to be expected in peak storms.
- Visualize a level tabletop terrace with water on it. During a heavy rainstorm, water depth can increase quickly unless all of the water soaks into the soil. Water will soon spill over a completely level bench terrace when the downpour comes faster than the soil absorbs it.
- If you have any doubt about the bench terrace floor holding all the water in a peak rainstorm, do not use a 0-percent slope. The risk is too great. Use a 5-percent inverse slope instead.
- Make accurate measurements at each step. If you do not, the entire slope that has been cut and filled will be susceptible to quick serious erosion.
- If you use the “A-frame,” keep in mind that it is probably accurate only to 1 percent plus or minus. Therefore, slope the terrace about 1 percent on the contour in the direction of the exit ditch and slope the bench 2–5 percent inward (pointing uphill). Then, during rainstorms, excess water will not spill over the outer edge of the bench platform and destroy the terrace, but will soak in or move slowly around the contour to the control drainage ditch.
- When constructing bench terraces and calculating slope (the final slope you want), allow for settling of the bench floor. Remember that the outward half of the bench has the loosest soil. Even though you pack this dry soil by walking on it, it will settle further after rainwater has percolated through it. This will give a downward slope, causing the terrace tabletop to wash away badly. So, if the desired inward slope is 0 percent, 1 percent, 3 percent, or 5 percent, add another 5 percent to the measurement of the slope of the bench top. The farmer may still need to make minor adjustments during the next dry season after the rains.
- In most cases, you will want to build up the outer edge of the platform floor with a small ridge (20 centimeters wide and 15 centimeters high) covered with grass. This grass should overlap with the grass growing on the riser (wall side of the terrace).
- As the soil is cut out for the terrace, set the topsoil aside and pile it together. After the terrace is formed, re-spread the topsoil over the same section. This is the richest part of the soil!
- Take extreme care to connect the dry soil thoroughly.
- Be sure to establish a solid stand of grass on the riser (the vertical bank). These sloping banks of earth must be covered with vegetation at all times. Check the plantings of grass at frequent intervals and plug grass into the bare spots as part of a constant maintenance program.

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- Accurately estimate the average percent slope at different sites up and down the hill. It will vary!
- Carefully measure the useable soil depth on different slopes up and down the hillside and in different parts of the field.
- Check the accuracy of the A-frame several times a day.
- Construct all bench terraces in the dry season. Allow enough time to complete the projected terraces before the heavy rains.
- Begin at the top slope of the field. (Note: Some people begin bench terraces from the bottom, but it is much safer to begin at the top.) First construct a diversion drainage ditch on the contour across the field to intercept and control water flowing down from above the field.
- Begin terrace construction immediately below the ditch. Do the work in small increments. Save the topsoil and place it to one side to be redistributed when the cutting and filling on a section is complete.
- For more information on how to build bench terraces, see the Peace Corps manual Soil Conservation Techniques for Hillside Farms [R0062]. Much of the above information is based on this excellent publication.

Figure 4-21. Using an A-Frame to Determine Contour Lines

Photo c/o creativecommons.org



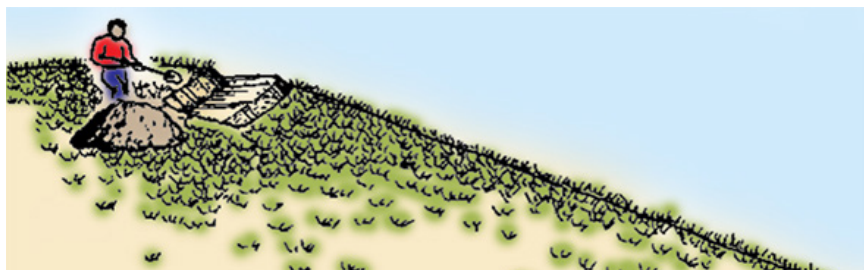
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How to Build a Continuous Bench Terrace

1. Be sure the farmers understand the whole labor-intensive process—the many days of hard work and the cutting, digging, and filling involved. Consider possible questions and needs for the farmer, while anticipating any problems. Take your farmers to visit other farmers who are using bench terraces successfully. Visit any technicians who are working with them as well. Your farmers may have to travel a long distance to do all of this, but you will be glad you took them.
2. Investigate existing or potential markets for at least some of the crops. Is there a good market for particular crops? Are there vegetables or other high cash value crops? Can the farmer find other crops that have better cash value and more demand? How can the farmer increase the crop yields?
3. Assemble heavy-duty hoes, few shovels, many stakes, some strong string, small string level, and a clipboard to hold papers and notes.
4. Dig a number of pits in the field to determine the depth of useable soil. Be sure it is adequate: The vertical height of the terrace bank can be no more than two and one-half times the depth of the good soil. Dig test holes up and down the slope to check the depth. Determine what crops the farmer can grow that will justify an expensive terrace.
5. After the hilltop diversion ditch is finished, begin the topmost segment nearest the drainage side of the field. Remove the topsoil from a 2-meter segment and pile it on one side to be spread back on top of the segment after the subsoil has been shaped as a bench terrace. (Figure 4-22).



6. Form a well-compacted segment of terrace making sure it is measured correctly to grade. (Figure 4-23).



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7. Distribute the topsoil back over the same 2-meter section and pack it down well. Then clear another 2-meter section of topsoil and form it the same way as a terrace section. (Figure 4-24).



8. Continue work with the top terrace, going in 2-meter segments sideways around the hill. After the full length of the top terrace is completed, begin the next lower bench terrace in the same manner as the first. (Figure 4-25).



9. Continue work down the hillside. Work always begins on the drainage side of the field. Each terrace should have 1 percent slope toward the drainage side. Check with local technicians. (Figure 4-26).



10. Plant slips of grass on the terrace banks (risers). If possible, also use some straw or leaf mulch on the risers. Also mulch the outside half of the terrace floor where most of the fill has been made. This will help reduce erosion of this newly disturbed soil. (Figure 4-27).

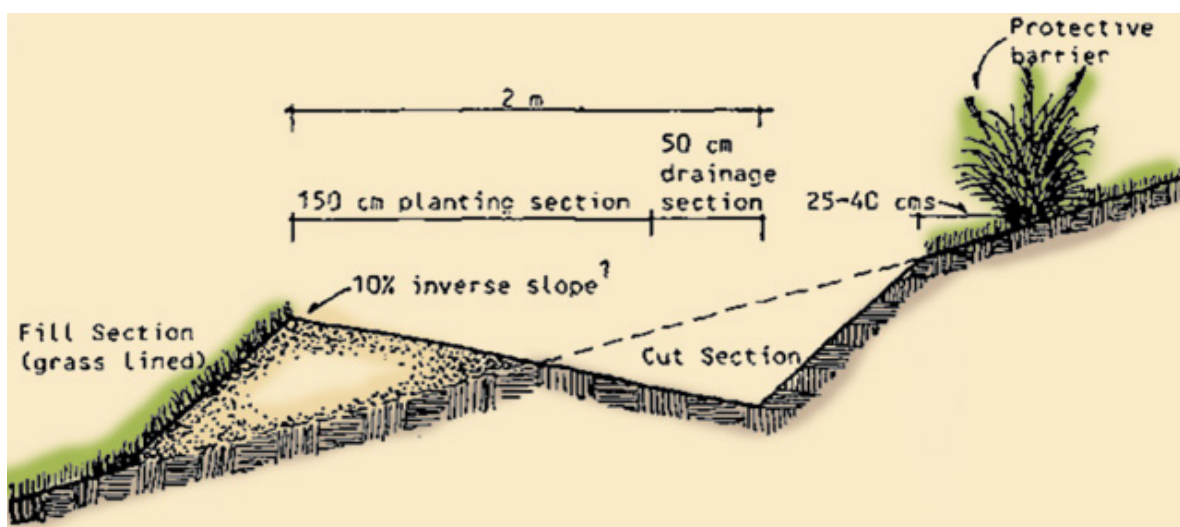


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Steps for Building Intermittent Discontinuous Terraces

1. Accumulate tools and supplies for building continuous terrace.
2. Pack loose-filled soil.
3. If grass slips are not available and grass seed is planted, apply a mulch cover, especially to the fill section (the outside part of the terrace floor) and to the inside terrace wall (the riser).
4. Begin at the top of the field with an appropriate contour diversion ditch. Add other drainage ditches, including a controlled exit drainage ditch as needed.
5. Build discontinuous terraces on the contour with an inverse (inward) slope of 10 percent. Note that when the bench top is tilted this much inward, the inside cut (inside edge of the bench) forms a rather wide "V" with the bank at the innermost edge. This acts as a small drainage ditch to carry excess water away to the controlled drainage ditch.
6. The terrace will act as a conduit for unabsorbed surplus water, which will naturally follow the downward slope. Therefore, slope the terrace 1 percent along its entire contour, toward the direction of a drainage control ditch.

Figure 4-28. Vertical Cross-section of a Discontinuous (Intermittent) Narrow Bench Terrace

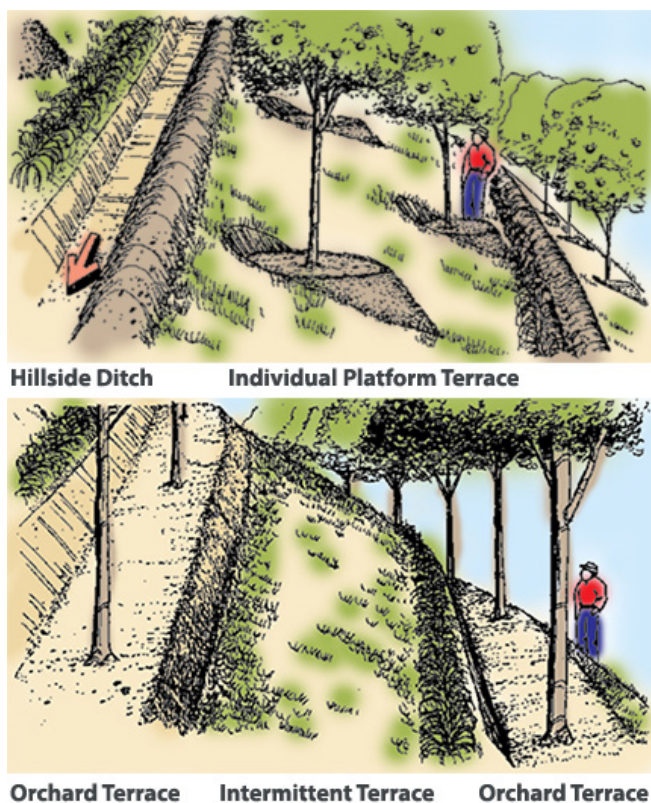


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Steps for Building Individual Platform Terraces

1. Protect the terraces with a standard contour diversion ditch at the top of the field and other contour drainage ditches as needed.
2. Plant one tree on each platform and stagger the platforms over the hillside in an equilateral triangular or hexagonal pattern. This prevents the formation of straight rows down the hillside that make a path for runoff water. The distance between platforms will vary from 2 to 5 meters or more, according to the type of trees being planted. Get advice about this from local PCV agriculture specialists.
3. As the terrace is cut out, reserve the topsoil in a pile and return it to the top surface of the terrace. Compact the soil as shown.
4. After construction, be sure to cover the terraces with mulch. These terraces must be protected by mulch.
5. Also, plant low-growing vegetation to form a solid cover on the ground level, side, and top of the platforms and the slopes between. This is vital because the system erodes easily. Consider a legume-grass combination.

Figure 4-29. Intermittent (Discontinuous) Terraces used for Orchards



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Note: In the top drawing are individual platform terraces used for growing different kinds of trees on very steep slope. Below it is a sketch of orchard terrace. It is critical that all land between these types of terraces be covered with plant material, preferably a combination of grass and a low-growing legume (but not a climbing legume vine). These terraces must also be protected by drainage ditches. (Drawing from Soil Conservation Techniques for Hillside Farms [R0062]).

Table 4-10. Bench Terrace Construction Guide

Slope percent	Useable Soil Depth (Meters)	Total Terrace Width (Meters)	Terrace Platform Width (Meters)
20	0.3	2.5	2.0
	0.4	3.3	2.6
	0.6	5.0	3.9
30	0.3	1.7	1.2
	0.4	2.3	1.6
	0.6	3.5	2.4
40	0.3	1.3	0.8
	0.4	1.8	1.1
	0.6	2.7	1.7
50	0.3	1.1	0.60
	0.4	1.5	0.80
	0.6	2.2	1.20

Source: Modified from Soil Conservation Techniques for Hillside Farms. 1986.

Table 4-11. Discontinuous Narrow Terraces Construction Guide

Slope	Distance between Terraces (meters)	Total Terrace Width (meters)
5	18	2.2
10	14	2.3
15	13	2.4
20	12	2.5
30	12	2.7
40	12	3.0
50	12	35*

**GGW estimate*

Source: Modified from Soil Conservation Techniques for Hillside Farms. 1986.

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Introduction

Forests cover 31 percent of the land area on our planet. They produce vital oxygen and provide homes for people and wildlife.

However, forests around the world are under threat from deforestation, jeopardizing these benefits. Deforestation comes in many forms, including fires, clear-cutting for agriculture, ranching and development, unsustainable logging for timber, and degradation due to climate change. This affects people's livelihoods and threatens a wide range of plant and animal species. Some 46,000–58,000 square miles of forest are lost each year—equivalent to 36 football fields every minute.

Forests play a critical role in mitigating climate change because they act as a carbon sink—soaking up carbon dioxide that would otherwise be free in the atmosphere and contribute to ongoing changes in climate patterns. Deforestation undermines this important carbon sink function. It is estimated that 15 percent of all greenhouse gas emissions are a result of deforestation.

Deforestation is a particular concern in tropical rainforests because these forests are home to much of the world's biodiversity. For example, in the Amazon around 17 percent of the forest has been lost in the last 50 years, mostly due to forest conversion for cattle ranching. Deforestation in this region is particularly rampant near more populated areas, roads, and rivers. However, even remote areas have been encroached upon when valuable mahogany, gold, and oil are discovered.

Without trees to anchor fertile soil, erosion can occur and sweep the land into rivers. The agricultural plants that often replace the trees cannot hold onto the soil. Many of these plants—such as coffee, cotton, palm oil, soybean, and wheat—can actually exacerbate soil erosion. Scientists have estimated that one third of the world's arable land has been lost through soil erosion and other types of degradation since 1960. In addition, as fertile soil washes away, agricultural producers move on, clearing more forest and continuing the cycle of soil loss.

Slash-and-Burn Farming

Slash and burn is an agricultural technique that involves cutting and burning of trees and plants in forests or woodlands to create fields. It is subsistence agriculture that typically uses little technology or other tools. It is typically part of shifting cultivation agriculture, and of transhumance livestock herding.

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A farmer clears a small plot (1 hectare more or less) by cutting down most of the trees and tall brush. The farmer burns most of the residues as an easy way to get rid of weeds and trees. After growing crops for two or three years, the farmer moves on and clears another place. The first farm plot rests fallow (i.e., without cultivation or cropping) for 10 to 20 years, returning to forest.

For thousands of years, tropical small farmers have practiced slash-and-burn farming. The forest fallow system kept the land in good condition indefinitely, even though some minimum erosion did occur. In those days the cleared land was not too steep. Forest trees and shrubs soon re-established themselves when the land was left to lie fallow, gradually replenishing the organic matter and fertility of the soil.

Where land is plentiful, the system still works and is sustainable. However, intense population pressures are causing it to break down. As land gets scarce, farmers must clear steeper land and must farm the same land for more than three years. Often they cannot move on to other land at all. Soon the soil on steeper slopes washes away and nutrients in the soil are depleted. After the soil is degraded and no longer useable, many families join the millions in city slums. The breakdown occurs because many forest soils on steep slopes must have regeneration equivalent to forest fallow, or improved management that results in a sustainable system.

Alternatives to Slash-and-Burn: Slash-and-Char Farming

Slash-and-char farming is an alternative to slash and burn that has a lesser effect on the environment. It is the practice of charring the biomass resulting from the slashing, instead of burning it as in the slash-and-burn practice. The resulting residue matter (charcoal and biochar) improves the soil.

In that context, charcoal can be made by numerous and varied methods, from the simplest (an earth cover on the pile of wood with strategically placed vents) to the most sophisticated (a modern plant that recuperates and recycles strictly all exhaust gases).

Slash and char offers considerable benefits to the environment when compared to slash and burn. It results in the creation of biochar that can be mixed with biomass such as crop residues, food waste, manure, and/or other, and buried in the soil to bring about the formation of terra preta. Terra preta is one of the richest soils on the planet—and the only one known to regenerate itself, although precisely how this happens is hotly debated within the scientific community.

It also sequesters considerable quantities of carbon in the safest and most beneficial fashion, in contrast to the negative effects of the slash and burn. Switching to slash and char can sequester up to 50 percent of the carbon in a highly stable form.

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Agroforestry

Another way to combat deforestation is through agroforestry. Agroforestry includes both traditional and modern land use systems where trees are managed together with crops and/or animal production systems in agricultural settings. When practiced at scale, it can enhance ecosystems through carbon storage, prevention of deforestation, biodiversity conservation, cleaner water, and erosion control. At the same time, it enables agricultural lands to withstand events such as floods, drought, and climate change.

Agroforestry is not new. It builds upon farmers' traditional knowledge, expanding and promoting it. Many developing world farmers have traditionally practiced a type of agroforestry. When they cleared fields for crops, they left in the fields the useful trees, like acacia, dawa-dawa, and many others. If made a part of planning and development, villagers often become committed boosters.

Agroforestry can usually implement ways and concepts that individual families can understand and manage without much outside help.

Agroforestry researchers and specialists have been devising and working out ways to incorporate trees into the farming system. They stress the urgent need for trees on small farms. Even degraded land will often sustain some types of badly needed trees.

Many development experts believe that only the millions of small farmers and villagers themselves can solve large-scale deforestation. Their numbers are so overwhelming that only they can provide enough knowledge, labor, and commitment for a problem of such scope. They are on site and trainable.

In Kenya, for example, villagers have planted many more trees than have been planted on government plantations. In Rwanda, trees planted by rural people total about 20,000 hectares—more area than the remaining natural forests and state and communal plantings combined.

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Gender and Agroforestry

Agroforestry extension agents need to be aware of gender roles and responsibilities in order to avoid the suggestion and implementation of practices that may disproportionately benefit one group over another, or which disproportionately increase the labor requirements of certain members of the community. Men and women have different responsibilities, differential access to resources, different kinds of natural resource and agriculture knowledge, and different interests and objectives that they accomplish through particular practices and claims to resources. Without understanding how men and women relate with each other, poorly conceived agroforestry extension that does not consider power relationships can have detrimental effects on some groups or on society as a whole. For example, in his book *Shady Practices: Agroforestry and Gender Politics in the Gambia*, Richard Schroeder found that men formed alliances with forestry extension agents in order to displace market gardens that were controlled by women and provided them with an important source of income. While introductions of certain practices may inevitably bring social change, Volunteers must be careful that such introductions do not further marginalize already marginalized populations.

Source: Schroeder, Richard A. 1999.

Agroforestry Defined

Agroforestry systems use trees as part of a farming program that includes growing other crops. It often also includes raising animals. In agroforestry systems, the farmer grows trees to prevent erosion and replenish the soil, and also to provide food, feed, firewood, and income.

Benefits of Agroforestry

Agroforestry systems can offer advantages over conventional agricultural and forest production methods, which include:

- With two or more interacting plant species in a given land area, such systems create a more complex habitat that can support a wider variety of birds, insects, and other animals.
- Reducing poverty through increased production of wood and other tree products for home consumption and sale.
- Contributing to food security by restoring the soil fertility for food crops.
- Providing clean water through reduced nutrient and soil runoff.
- Reducing deforestation and pressure on woodlands by providing farm-grown fuelwood.
- Reducing or eliminating the need for toxic chemicals (insecticides, herbicides, etc.).
- Improving human nutrition through more diverse farm outputs.

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- Helping fight climate change by storing carbon. Carbon, sequestered by trees intercropped with food and fodder crops and stored in aboveground biomass and soil, contributes to reducing greenhouse gas concentrations in the atmosphere.
- Buffering against weather-related production losses such as reduction of soil erosion through measures like hedgerow and contour planting, thus enhancing resilience against climate impacts.
- Bringing nutrients from deeper soil layers, or in case of legume trees, through nitrogen fixation, which can convert leaf litter into fertilizer for crops.
- Providing additional income and diversity of food sources through tree-based products.

Trees as Replenishers of the Land

Reforestation can use some degraded lands and restore them to usefulness, resulting in the following:

- Tree litter (leaves and twigs) left on the soil surface prevents raindrop splash erosion. The protective cover also conserves soil moisture by reducing evaporation.
- Added organic matter from decomposing forest litter (tree limbs, twigs, leaves, mulch) improves soil fertility, structure, and permeability to rainwater; it diminishes rainfall runoff.
- Many legume trees (and a few other kinds) produce nitrogen fertilizer that rapidly increases the soil's productive potential (See Chapter 3.) Nitrogen-fixing trees can often reduce fallow time needed for depleted land from 10 or more years to very few years.
- The deep and wide-spreading root systems of trees interweave throughout the soil and work the soil to great depths.
- Very long tree roots penetrate the soil more deeply than field crops and bring up plant nutrients from the subsoil, which recycle when leaves and twigs return to the soil.
- Trees and tree mulch shade the soil and protect it from hot tropical sun, keeping the soil from baking. This creates a better macroclimate and microclimate. The cooler soil temperature also encourages more root growth and helps conserve organic matter.\

Trees as Crops and Income for the Farmer

There are also a number of ways for trees to provide income for farmers:

- Trees can provide stakes, poles, lumber, fibers for weaving, and wood for crafts and furniture manufacturing.
- Many species make valuable forage, either for grazing or for cut-and-carry. Certain kinds can provide fodder during the dry season or during droughts when other animal feed is extremely scarce.

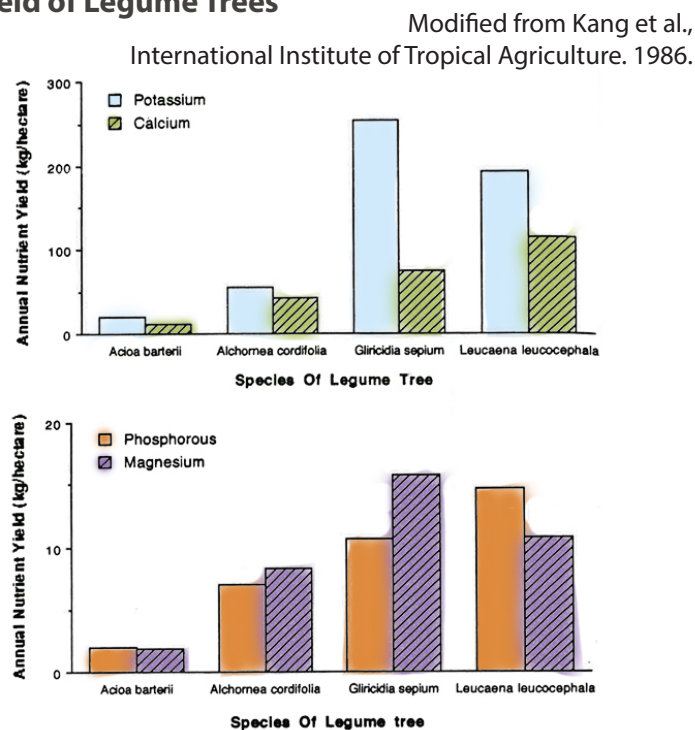
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- Pods, seeds, fruit, and nuts from trees provide food, which can greatly improve a family's diet and income. Certain kinds provide cooking oil; some even make fermented drinks.
- Some species provide nectar for honeybees, leading to beekeeping as an enterprise.
- Legume trees can provide nitrogen and mulch for improved crop yields and, at the same time, produce other tree products.

As with soil conservation techniques, motivating farmers to plant trees has proven to be extremely difficult unless the trees address one of the farmers' short-term needs—and since trees are long-term commodities, this has been challenging. Finding short-term payback strategies seems to be a key element in a successful community forestry project.

Peace Corps successes have included coupling beekeeping, fruit production, cut-and-carry forage production, and in some cases wood-lot development to provide incentives for tree planting and maintenance. Live fences provide another example of a successful motivator, with farmers using trees for wind breaks in arid regions.

Figure 5-1. Nutrient Yield of Legume Trees



Note: Some legume trees, when planted in rows 4 meters apart, not only produce nitrogen, but also recycle other plant nutrients. For example, the deep root system of Gliricidia sepium withdraws heavily from the soil—more than 200 kilograms of potassium, 50 kilograms of calcium, 15 kilograms of magnesium, and 10 kilograms of phosphorus per hectare per year. Much of these plant nutrients are returned to the soil as the tree leaves drop, or as they are harvested and spread over the soil surface as mulch. Leaves of legume trees could also improve the quality of compost.

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Systems of Tree Planting for the Small Farmer

- Native trees and vegetation. Where available, they supply the main fuel and some food sources for many rural subsistence families.
- Planting around homes, in cropland, pasture, or field. Trees are located at random in grazing land to give shade for animals and fodder to use during dry periods.
- Trees as live barriers combined with green manure crops to control erosion and improve soil fertility.
- Alley cropping (see later section of this chapter). Also known as 'hedgerow intercropping,' "alley farming," and various other names.
- Multi-tiered planting. Crops of different heights growing together. They often include leguminous trees, shrubs, and cover crops.
- Trees grown in stands for lumber, firewood, poles, fruit, animal feed, or other needs.
- Community or farm woodlots. Trees on the village commons or a farm on designated land.
- Farm fodder feed banks. Farmers often concentrate trees for cut-and-carry fodder in stands or blocks to ensure easy harvesting and location near penned animals. Small blocks thickly planted with trees can also be more easily fenced to keep out foraging animals.
- Trees along fence lines, farm boundaries, roads, and stream banks; around homes or compounds; on terrace risers; in ditches.

Figure 5-2. Gliricidia Sepium

Photo c/o creativecommons.org



Note: Gliricidia can be trimmed back, their leaves fed to livestock, and their limbs used as firewood. They also makes an excellent green barrier when planted close together, as instructed in Chapter 4.

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How to Establish Agroforestry in your Area

Successful agroforestry projects are not easy to establish. Many have failed in the past. Farmer commitment, the main requirement of success, depends on:

- Consulting the farmers and using their knowledge
- Making farmers and villagers part of the planning and action
- Respecting traditional customs and lore
- Using species the farmer likes (usually a multipurpose tree)
- Meeting the farmer's perceived needs
- Increasing total yields or income
- Protecting trees from damage
- Clear understanding of obligations and benefits by participants in cooperative programs.

Steps to Establish Agroforestry

1. Know your area. Determine the kinds, extent, and productivity of trees that are already growing, and varieties that are doing well. Investigate weather, soil types, elevations, special problems, and special needs.
2. Consult with foresters, your Associate Peace Corps Director (ACPD), other Agriculture Volunteers, and others. Find out recommended varieties and sources of seeds, cuttings, or seedlings. Study local lists of recommended species used by a researcher.
3. Check for local sources of seed and seedlings. Also look for other sources.
4. Visit local farmers. Learn how long each farm has been under continuous cultivation and explore problems with erosion or diminishing crop yield. Determine the farmer's tree needs and preferences. How far must people go for firewood and fodder? What fruits are used in the family diet? Involve the farmer.
5. Visit local village and co-op leaders. Determine needs, marketing problems and possibilities, ideas, and preferences. Get their inputs. They will have very practical experience.
6. Arrange group meetings. Hold open discussions. Be sure to include women farmers and the wives of farmers. Together with them examine concerns such as: need for more animal feed during the dry season or at any other time, for more firewood in the home or locally, for other wood products, for more fruit trees; other needs for trees (e.g., income

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generation); favorite or appealing types of trees; concerns about tree planting; and other concerns. Also examine possibilities for growing more trees on the village commons or in communal plots, growing legume trees as live barriers if erosion is a problem, and growing multipurpose trees as windbreaks.

7. Take interested farmers and village leaders, along with a forester or extension worker, to visit successful farmers or village tree-growing demonstrations.
8. Hold small meetings, workshops, and audiovisual presentations to raise general awareness, create hope and enthusiasm, and set a tentative goal. Again, examine together what factors limit growing more trees.
9. Involve youth groups: scouts, school classes, 4-H programs where available, and others. They can raise a few seedlings for the market or possibly help with village projects or reach their own goals.
10. Introduce the idea of alley cropping if rainfall is adequate (1,800 millimeters or more), and if the desired multipurpose legume trees do well in your location.
11. Encourage establishing individual farmer small nurseries and community nurseries. Discuss the formation of village tree-growing clubs. Look at marketing possibilities for tree seedlings.
12. Help decide on tree varieties for each farmer's particular needs. Consider the growth rate of various trees and how soon does the farmer need income from them? What are the advantages, disadvantages, and special growing requirements for different varieties? Determine the advisability of growing a mixture of varieties to minimize the risk of loss from disease and insects.
13. Plan labor needs if tree-planting time conflicts with crop planting time; careful scheduling or neighbor cooperation should be included in the planning.
14. Plan follow-up care of young trees, keeping the young trees weed-free and protected from drought.
15. Determine how to protect trees from grass fires (i.e., by constructing fire lanes, other methods).
16. Develop ways to protect trees from animals.

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Desirable Types of Trees

Legume Trees

As noted throughout this manual, legumes adaptable to the region, in whatever size or shape (adaptable low-growing ground cover, shrubs, or trees), are premium choices for soils low in nitrogen.

Multipurpose Trees

Ordinarily, the farmer needs trees that have multiple purposes (multipurpose trees). For example, a nitrogen-fixing tree might furnish fodder, firewood, nitrogen fertilizer, green manure and poles; its pods or seeds might provide food for the family. Field workers report that farmers will plant multipurpose trees when they do not want to plant trees specifically for firewood or for improving the soil.

Fruit Trees for the Family Compound

Many desirable fruit trees thrive in the tropics and have great value for the health of the family. Citrus trees are, of course, noted for vitamin C, but others, like the avocado and the banana, are highly nutritious. Also, do not forget mango, guava, coconut, papaya, and nut trees such as cashew.

Family nutrition often suffers when lands are diverted from family food crops to crops for market. Fruit trees can help fill the gap.

Following are a few fruit trees or shrubs with time needed from planting to harvest:

- Bananas: 11 to 14 months
- Papaya grown from seed: 6 to 9 months
- Citrus (lemon, orange, grapefruit, tangerine): about 7 years, but then they produce for many years with good care
- Mango: begins to produce in 3 or 4 years, and produces for many years
- Guava: grafted trees begin to produce in 5 or 6 years, and produce for many years.

Plant fruit trees, shrubs, or vines in well-drained soil with a lot of compost. Each year, add leaves, manure, and other mulch to the soil under and around fruit trees.

Answers to Farmers' Concerns about Growing Trees

“Trees take too long before harvest time.”

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Many varieties grow quickly. Farmers can plant fast-growing trees (like bananas and papaya) while slower growing kinds are coming along. The need here is to locate and plant some desirable fast-growing varieties. Nutritious fruit is worth some wait. Other crops can grow along with the trees to provide food and income.

“Trees shade crops.”

Many multipurpose trees can be cut back or one can prune their branches to eliminate shade competition during the food crop growing season. The trees can then grow freely during the dry season, providing fodder when little else will grow. Rows of trees may be spaced more widely if needed.

“Trees take up land area that could be put to crops.”

The trees occupy little space when they are small or when the farmer keeps them pruned. Even if a little crop area is lost, many multipurpose tree products add to the total income when combined with crop yields.

“I failed with trees before.”

Some farmers might not have been successful with trees due to animal damage and neglect of plants in other ways (weeds, drought when young, grass fires, etc.). Proper management is extremely important, especially care for very young plants. This is a vital consideration. Discussing ways to protect plants and perhaps plans for cooperative action is important.

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How to Grow Trees?

1. Planning. Select the kinds of trees to be planted and decide where to plant them. Locate seed, seedlings, and/or cuttings to plant, if possible, from healthy, well-known trees in the area. Encourage the farmer to test-demonstrate an area with new recommended varieties of multipurpose legume trees.
2. Make the seedbed. Make a slightly raised seedbed 6 to 10 centimeters above the surface to give good drainage. Be sure it is protected from any runoff water from above. Make the bed no more than 1 meter wide so that it can be tended from both sides without walking on the bed. Make the soil mixture from good topsoil plus some organic matter (well-decomposed manure or compost). Work the soil well until it is composed of fine particles and is smooth in texture.
3. Plant the seed. Plant seed in very shallow trenches made with a small stick or with your finger. The rows should be 4 centimeters apart. (Note that some kinds of seeds need to be pre-soaked—others may need special treatment.) Cover lightly with soil and then with mulch. Water gently with some kind of sprinkling can that puts out very fine drops. Be sure the bed is slowly soaked well. Keep the bed moist.
4. Tending the plants. Water the bed daily with the sprinkler can. Hold the sprinkler can low and apply the water gently. Shade the soil from hot sun and protect it from raindrop splash. Depending on the climate, build a frame roof covered with grass or straw about 1 meter high and 1 meter wide above the seedbed. This protects the tender seedlings from large raindrops and from full sunshine. Keep the bed free of weeds. When the seeds have sprouted, remove part of the grass mulch (enough for the seedlings to emerge). Some remaining mulch can help shade the soil and prevent too much raindrop splash. Thin the plants when the seedlings have grown their first two leaves. Leave plants in the bed 4 centimeters apart in each desired row and transplant the seedlings into another bed or into containers to grow.
5. Plant directly into containers or plant in beds and then move the seedlings to containers as they grow. Mix soil for containers much as above, adding some sand if possible (one part sand, one part old manure or compost, and one part good topsoil). Use small plastic bags to hold the potting soil, or small paper cartons, wooden boxes, tin cans, plastic jars, or containers woven from palm leaves or other local material. Poke small holes in the bottom to facilitate drainage and prevent root rot. Place containers under partial shade. Water gently daily or as needed.
6. Transplant seedlings. Seedlings will be ready to transplant into the field when they are 1 year to 18 months old, or sooner depending on growth rate. Always begin transplanting at the early part of the rainy season. Handle the seedlings carefully. Do not let them dry out. Be careful not to expose the roots to wind or sunshine. If possible, keep a ball of wet soil around the root. If the seedlings grew in a container, remove the soil intact when wet and plant the entire clump of soil and roots. Plant the seedling into the ground at the same depth it was planted in the seedbed or container. Keep the plant in an upright

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position while planting so that the taproot stays vertical, is not bent, and will grow. If seedlings are planted too shallow, some of the roots will be exposed.

7. Protect transplanted seedlings. Transplanted seedlings are vulnerable to animals, weed competition, fire, heavy rains, and drought.
 - In case of drought a few weeks or months after planting, carry water to the forest demonstration and irrigate each tree until the drought is interrupted. Watch for wilting. Place some mulch around each tree. It will help control weeds and conserve soil moisture.
 - Fence the forestry plot to keep farm livestock away or the trees may be destroyed; or else fence or tether livestock. Do not allow animals near. Damage from farm animals is a major constraint to growing trees.
 - Make needed fences from local material. Usually low-cost or no-cost local materials such as bamboo, cornstalks, or tree limbs will make a suitable fence to keep out small animals. Sink the limbs or stalks into the ground and tamp them firmly. Use vines, raffia, other native fibers, or string to weave around and through the stalks at two or three heights to form a fence similar to a picket fence.
 - If this is impossible, devise some solution to keep animals out. Some farmers have used thorn bushes or cacti barriers as fencing. A project in India dug deep ditches, surrounding plots to keep cattle out. Farmers acting together might hire guards or use family members as guards.
 - Be faithful in keeping the tree plot free of weeds in order to reduce weed competition for moisture, nutrients, and sunshine.
 - Keep an open fire lane, clear of any dry burnable materials, around the plot.
8. Harvest tree products. When to harvest depends on the tree variety; how the wood, branches, leaves, fruits, and seeds will be used; the age and growth of the tree; the market demand; and factors such as whether the tree is intended to grow tall or is to be kept small and bushy.
 - Quick-growing trees like the legume *Gliricidia* can, at 1.5 to 3 years of age, be harvested back to 1 meter of height for firewood, and at 2 to 3 years of age for poles. They can be harvested again, as needed, at any time for green manure, firewood, or animal feed.
 - Eucalyptus can be cut for posts or poles at 5 or 6 years. Smaller limbs can be cut earlier for firewood or to make charcoal.
 - Trees can be allowed to grow large for lumber or for paper or chemical production.
 - Firewood can be harvested by pruning the tree.
 - Certain multipurpose trees provide animal fodder at many stages of their growth. Seeds, pods, fruits, and nuts for human consumption usually grow on the trees until mature or ripe.
 - Legume trees can be pruned as needed for mulch or green manure.

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Figure 5-3. Protecting Young Seedlings in the Field



Note: If straw mulch is not available, some very young, fast-growing seedlings can be protected from heavy rains and full sunshine by placing other types of protection over them. In the image above, Peace Corps Volunteers and their counterparts cover the planted seeds with mulch (left) and neem tree stems (right).

Figure 5-4. Construction with poles (instead of finished lumber) is common in tropical countries, especially in rural areas.



Community Agroforestry Seedling Nursery

A nursery may not be needed for certain trees. Gliricidia, for example, will grow from green stakes driven into the ground during the early rainy season. Fast-growing trees with large seeds will grow from direct seeding. *Leucaena leucocephala*, though slow to grow the first few months, can be planted directly into the maize row at the time maize is planted. Weeding the corn also weeds the *Leucaena*, which establishes itself well while the corn grows.

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Most young tree seedlings, however, are very fragile and do much better when started in a nursery. A nursery can also protect them from hot sun, rain, drought, animals, and other damage. In the nursery, seedlings can be grown and kept watered through the dry season to be ready to set out during the early rainy season.

A nursery also makes possible a reserve bank of seedlings or small trees for farmers starting agroforestry, or for a backup supply in case of shortages.

How to Establish a Community Seedling Nursery

Supplies:

- A plentiful pile of rich topsoil.
- Old manure or good compost or both piled and ready.
- A pile of sand to be added to help form a potting mixture.
- A sled or wheelbarrow to carry pots, soil, etc. If necessary, you or the farmer can build one.
- A source of pots or other plant container. You may find plastic film tubing that tears off in short sections to become a small sack. Use whatever containers you can make or find. Some farmers use small woven baskets or sections of large hollow bamboo limbs cut to proper length (18 to 20 centimeters), depending on the size of the plant to be grown. Some types may require a much larger container. Whatever you use, be sure small holes can be punched into the bottom to allow drainage of the surplus water.
- Tools: You will need knives (cutlasses or machetes), shovels, hoes, spades, mattocks, sprinkler cans, and buckets.
- If possible, make a frame of wood poles or lumber about 3 or 4 centimeters thick and 6 to 8 centimeters wide. The frame should be about 45 centimeters by 45 centimeters or larger. It should be covered with coarse galvanized screen of about 1.5 centimeters square mesh. This will be used to screen out large clods and rocks when mixing soil for the small pots.

Instructions:

1. Determine the purpose and the size of the nursery. How many seedlings will be needed? What kinds? When will different varieties be needed? At what age will the trees be ready to transplant?
2. Select the people to help you. You will need very reliable help.
3. Locate sources for healthy seeds or seedlings.

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4. Choose the site. It should be a level area if possible. The nursery needs to be convenient, accessible, and near available water. Ideally, part of the site should have partial shade from low- growing trees. Dig a contour drainage ditch around the upper sides to carry away any water from above. Be sure the site is well drained and that it will not have small ponds of water standing during the rainy season. Build a strong fence around the area to prevent damage from animals or children. Keep both out of the area.
5. Build a grass-thatched or other type roof over one or more areas, to keep seedlings out of direct sunlight and heavy rain. Make the shelter sturdy enough to stand up to winds from heavy storms.
6. Build another shelter that remains dry for storing seed, fertilizer, and supplies. Provide a third dry shelter tall enough for people to stand and work during rainy spells.
7. Test the soil at the soil laboratory, if available, for pH, phosphorus, and potassium. Follow the laboratory's recommendation. If not available, use the best topsoil available with an abundance of compost and manure.
8. Purchase the needed fertilizer and ground limestone (if required) to make a very fertile soil.
9. Mix a large batch of potting soil. Use one part topsoil, one part sand, and one part manure or compost.
10. Plant your seedlings in a small seedbed or small trays or boxes about 15–20 centimeters deep to use for planting seed. You can put these boxes or crates on a raised table to avoid stooping while working. They allow plants to be moved quickly and easily when weather or other needs dictate.
11. Fill the boxes or trays with good potting soil. Plant seeds as you would in any seedbed. Transplant seedlings later, as necessary, to small or large pots, to wider row beds in the nursery, or directly to the field.
12. Build up a supply of mulch material. Grain straw (wheat, barley, rice) is excellent mulch. If not available, use dry leaves or other material to form a protective porous mat.
13. Seeds of some forest tree species need hot water or chemical scarification before planting. Legume tree seeds will also need treatment with Rhizobia bacteria. If there are no Rhizobia, they cannot fix nitrogen! You can treat the tree seeds with Rhizobia by rubbing them gently with soil from underneath a similar tree.
14. Sometime before transplanting, begin to harden the plants. Gradually remove them from nursery conditions to field conditions so they can survive in full sunlight.

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Figure 5-5. Village Tree Nursery

Photo c/o creativecommons.org



Note: Notice the framing for the shelter made of poles.

Figure 5-6. Planting Tree Seedlings in Pots

The Peace Corps



Figure 5-7. Plastic bags filled with greenhouse potting soil mixture.

The Peace Corps



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Alley Cropping

Tropical smallholders are often struggling to survive. These farmers have little cash and no credit to buy much fertilizer, chemicals, or special equipment. They have little education and little background in mechanics. They use hand tools and depend on hand labor, sometimes oxen, or water buffalo. They like and understand the methods of their ancestors; they distrust risky and strange ways. Some modifications and improvements of the old slash-and-burn system are needed.

Alley cropping solves the dilemma for some small farmers. It is not an outside system; it originated in Nigeria and builds upon traditional concepts of forest fallow. Farmers are accustomed to letting land lie fallow. They already farm with intercropping, multiple, and mixed cropping. For certain farmers and farming conditions, alley cropping can work well.

Alley cropping combines trees for forest fallow with continuous crop production in an intercropping system. It adds continuous use of forest fallow to continuous crop production.

In alley cropping, farmers grow trees in systematic rows or hedgerows, with food crops growing in the strips of land between the hedgerows. Some schemes include animal production. The rows of trees provide the benefits of forest fallow, even though food crops are growing along with them. Ordinarily, the farmer uses special leguminous tree varieties to add their nitrogen fertilizer to the soil.

As an essential part of the system, the trees are planted at intervals when food crops are planted or growing to prevent shade competition with the arable crops.

Sometimes, if the farmer does not plant food crops in the land strips, he or she allows the mature trees to grow without pruning in order to provide a shade over the soil to control weeds. The farmer can combine the system with periods of short or long fallow as he or she wishes. Often in such cases, the farmer allows livestock to feed on the lower leaves during a fallow period. (Caution: Be sure that the trees are at least 3 years old before animals graze, or the young trees will be destroyed.)

Alley cropping works best on soils that have not yet been heavily depleted and degraded. It has, however, produced good results on very poor, nitrogen-deficient sandy soil that had relatively fertile subsoil. Some work in arid and semi-arid regions shows that competition for moisture from the hedgerows adversely affects crop yields there. Much wider hedgerow spacing may solve part of the problem. In some cases, economic gain from tree and crop yields more than compensated for lower crop yields.

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Farmers in arid regions where fodder shortage becomes critical in the dry season can use trees for fodder when less deeply rooted plants do not grow. Thus, some form of alley cropping may be suitable in that situation.

Table 5-1. Advantages and Disadvantages of Alley Cropping

Advantages	Disadvantages
<ul style="list-style-type: none">• Under good conditions, provides a sustainable system that allows the farmer to grow crops year after year on the same land without degrading the soil. The rows of trees help keep soil organic matter and soil fertility relatively high.• Limits the land, which must lie fallow in trees to narrow rows, saving 80 percent of the farmland for crop production.• Is a land-efficient system of forest fallow. Caution: For this system to work, the subsoil must be relatively fertile and deep. The tree roots must find nutrients to recycle.• Applies appropriate technology—it builds upon systems the farmer knows, uses only tools he or she already uses, and requires minimum outlay of capital.• Adapts to many types of crops, crop uses, and cropping patterns.• Is highly useful and adaptable to systems of erosion control as live barriers.• Can provide useful fodder and forest products in addition to the farmer's yields of food crops, if sufficient trees are planted.• Under ideal conditions, can increase crop yields.• Can sometimes shade out many weeds if the farmer lets trees grow un-pruned during the dry season. The trees can form a canopy over the strips where food crops were harvested, discouraging weed growth.	<ul style="list-style-type: none">• Where the farmer is planning alley cropping for soil building, and does not need a live barrier for soil conservation, there may be other, better alternative farming systems.• The farmer should be sure of his land tenure or he or she should have a very long lease on the land, or own it. Trees are a long-term investment.• The subsoil should be relatively fertile and deep enough for tree roots to have depth and grow vigorously.• Most successful alley cropping to date has been done in humid and sub-humid regions. At present, alley cropping for arid and semi-arid regions should be approached cautiously and with an eye on future research results.

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How to Establish Alley Cropping

The following instructions are for level land. Steeper slopes call for careful contouring of tree rows and much thicker planting in the tree rows. The farmer should use the following as guidelines and adapt them to the particular situation:

- Familiarize yourself with methods of establishing and managing live barriers of nitrogen-fixing trees. Also, review the instructions for planting and growing trees given earlier in this chapter. Be sure the trees you plant are healthy, well adapted, and grow vigorously. Test all new species and varieties before expanding a demonstration.
- Although you will still plant two or three trees together in a cluster, space the clusters of seeds 10 to 30 centimeters or more apart in a row. If you have any doubt about erosion, run contour lines and treat the project as if you are establishing live barriers, using the thicker population recommended for them.
- Space the hedgerows according to the needs. Many researchers and farmers prefer about 4-meter spacing. On newly cleared soil, 4-meter spacing is usually ideal. If the soil is in poor condition, the farmer may need to space the tree rows as closely as 2 meters, provided that the soil moisture is adequate.
- If the farmer wants to stake climbing vines (yams, for example), plant a middle hedge of trees between the regular 4-meter rows. Space the trees in the center row farther apart and cut them back. The trunk, trimmed of branches, serves as the stake. If the farmer plans to grow trees for lumber, he or she will want them to grow larger and, therefore, will want much wider strips between tree rows and wider spacing in the rows.
- Adapt your alley cropping plans to the availability of soil moisture on reasonably deep and fertile subsoil. Where there is less rainfall, use spacing wider than 4 meters. Often the need for fodder in the dry season and for firewood may still make alley cropping desirable.
- Watch the outside row of the crop between rains. If leaves in the outside rows of crops are curling or wilting quicker than leaves in the inside rows (signs of moisture stress), then moisture is inadequate. One solution is to prune the tree roots. Cut down to a depth of 25 to 30 centimeters on both sides of the hedgerow, about midway between crop and tree rows. Slice straight down with a straight-edged spade, a hoe, knife, or cutlass. Do not slice down vertically through the soil.
- Consider using the recommended species (see below) or other locally grown nitrogen-fixing trees.

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Recommended Species for Alley Cropping

- **Leucaena leucocephala.** In non-acid or mildly acid soils it grows and produces exceptionally well, but it does not thrive in extremely acid soils. As noted elsewhere, Leucaena, the star performer of the legume trees, has become vulnerable to a bad leaf insect in Indonesia and the Philippines. The insect has not yet jeopardized Leucaena in other tropical areas. However, farmers should consider diversifying, i.e., mixing it with other varieties to minimize the risk. Leucaena used alone as fodder can cause mimosine toxicity. Farmers can solve this by mixing Leucaena with grass or Gliricidia in proportions of one to one.
- **Flemingia congest.** This legume is replacing Leucaena in Sloping Agricultural Land Technology (SALT) programs in the Philippines, where it is reported to be doing very well.
- **Gliricidia sepiu.** Another outstanding tree, second to Leucaena in production of foliage and nitrogen fertilizer per hectare. It is an excellent livestock feed.
- **Fodder trees.** See Table 5-2. For more acid soils, you can experiment with Inga edulis (sp). Some workers consider this a promising tree for some acid conditions.
- **Cassia siame.** This has been used with success in some studies by IITA in Nigeria.
- **Acioa berterii.**

Refer to <http://www.echocommunity.org/?LegumeCoverCrops> and <http://www.sare.org/Learning-Center/Topic-Rooms/Cover-Crop-Topic-Room>, both of which can provide information about how cover crops have been used and the multiple benefits they provide. Because particular goals of farmers vary, as do the local environmental constraints and opportunities, choosing an appropriate cover crop will be highly situational.

Figure 5-8. Banana Plants in Alley Cropping System

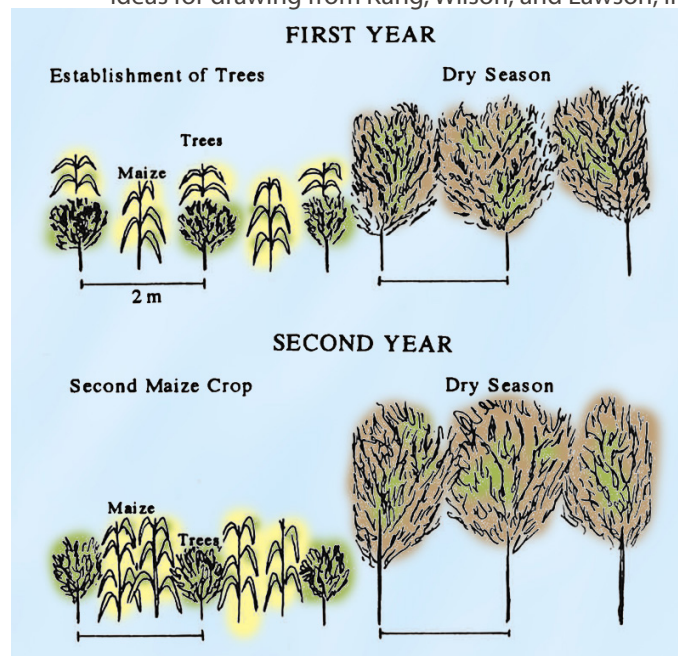
Photo c/o creativecommons.org



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Figure 5-9. Establishing Multipurpose Nitrogen-fixing Trees with Maize

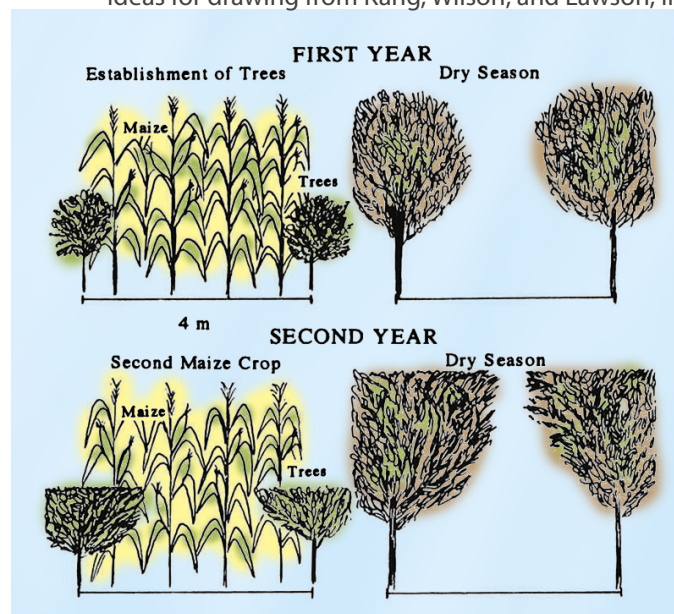
Ideas for drawing from Kang, Wilson, and Lawson, IIT



*Note: This is a diagram of the first two years' growth of *Leucaena leucocephala*, with rows of trees spaced 2 meters apart. Trees were planted at the same time the as maize, in the same rows as some of the maize, and with maize also growing by itself.*

Figure 5-10. Multipurpose Nitrogen-fixing Trees with Maize

Ideas for drawing from Kang, Wilson, and Lawson, IIT



Note: this shows trees with rows spaced 4 meters apart. The planting pattern was otherwise the same as in Figure 5-9. For most situations, the wider, 4-meter spacing between rows seems to be preferred by researchers and farmers using alley cropping.

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Desirable Characteristics for Trees to be Used in Alley Cropping

Most trees will not have all of these advantages; the choice depends upon the farmer's priorities.

- Well adapted to the climate and soil.
- Easy to establish.
- Quick growing.
- Profuse in foliage. Produces high volume of plant material (dry matter).
- Capable of producing 100 to 200 or more kilograms of nitrogen per hectare per year.
- Possesses a deep-rooting system. Able to recycle reasonable amounts of plant nutrients, especially calcium, magnesium, potassium, and phosphorus, from soil depths below the food crop rooting zone.
- Able to withstand lopping or pruning back to about 1-meter height at end of the dry season, and additional pruning during the food crop growing season.
- Quickly regenerative after pruning. Coppices well.
- Insect-, disease-, and drought-resistant.
- Multipurpose.
- Easily eradicated; has little potential for becoming a weed.
- Non-toxic and palatable if tree trimmings are to be used as feed.

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Case Study: Successful Agroforestry Project in Niger

During the 1970s and 1980s, farmers in the Sahel experienced severe drought and desertification. Drawing on their own experience and knowledge, farmers instigated widespread tree planting and seedling protection of important species that could provide food, fodder, fuelwood, and/or soil enrichment. Today, more than 5 million hectares of land have been reclaimed from the desert, which has had the effect of increasing food security through higher incomes and crop yields, such as millet.² The project is characterized by the following:

- Community-based planning: Villagers look at their priorities with regard to trees, examining their resources, their time, and local constraints. They discuss and analyze solutions, and decide on a plan of action.
- Recruiting volunteer tree promoters: In each interested village, contact persons (one or more) are chosen. They are usually influential persons in that village (school teachers, prayer leaders, etc.) who have shown enthusiasm for tree planting. The contact person takes responsibility for promoting tree planting, makes a list of interested people, and organizes the sale and distribution of tree seedlings.
- A Village Tree Committee is formed after acceptance grows in a particular village. It is composed of several farmers who have gained practical experience in tree planting and protection. The committee helps with awareness and usually starts local tree nurseries in its home compounds. Contact persons and the tree committee have a continuous responsibility for training villagers (who have ordered trees) in proper planting and protection of seedling trees. They are also responsible for continuing to build awareness.
- Training of Trainers: Once a year, usually just before planting season, all contact persons are invited to participate in a training workshop. They learn techniques for planting trees, establishing and maintaining nurseries, and protecting trees from animals and fires. They share experiences and practical problems.
- To ensure sustainability, as tree growing moves into an increasing number of villages, the tree committees have an association, which will take responsibility for getting its own seeds and sacks. They also have a village-based tree nursery, ensuring that they are not completely dependent on the central tree nursery run by the project leaders.

2 More information on this ongoing work can be found on the World Agroforestry website: <http://worldagroforestry.org/newsroom/highlights/incorporating-trees-agriculture-outstanding-success-re-greening-sahel>, <http://worldagroforestry.org/newsroom/highlights/niger-percentE2-percent80-percent99s-re-greening-revolution>, and the book *The Quiet Revolution: How Niger's farmers are re-greening the croplands of the Sahel*. <http://www.worldagroforestry.org/downloads/publications/PDFS/BL17569.PDF>

Ch 6: Helping Small Farmers on Very Steep Slopes

Introduction

Millions of poor, small farm families throughout the tropics live on very steep slopes, with some land sloping 40–60 percent. In many developed countries, such land remains idle or in forests; farmers do not cultivate it.

As populations increase, more people must try to grow food on steeper and steeper hillsides. Steep slope farming means farming under extremely difficult conditions and facing a number of problems—thin topsoil, quick and severe soil erosion, excessive water runoff, frequent lack of continuous soil moisture, inconvenience of farming and transportation, to name a few.

Appropriate technology can help these farmers. Throughout the developing world, certain farmers are already using methods that work even under these restricted conditions, with little or no outlay of capital.

This chapter outlines soil and water conservation techniques for very steep-sloped land, including the Sloping Agricultural Land Technology (SALT) method.

How to Conserve Soil and Water on Steep Slopes

1. Every possible erosion preventative measure is vital on a steep slope. Usually the topsoil is already very thin. It must not be lost!
2. Choose the right combination of water and soil conservation practices. Some combination will work successfully on steep slopes. Farmers on steep slopes have great need to use the methods in Chapters 3 and 4 as fully as possible. The steeper the slope, the more stringent the need.
3. Look at needs for more details. Use good contour and exit drainage ditches. On steeper slopes, contour ditches must be closer together. The choice of techniques will depend on soil characteristics (such as the permeability and the rooting depth of the soil), weather characteristics, resources, needs and desires of the farmer, and the percent slope.
4. If soil depth allows, consider a few bench terraces to be mixed with live tree barriers or in-row tillage or both.
5. On the steepest slopes, live grass barriers give way to live tree barriers. Consider intermittent orchard terraces.
6. Cover the soil surface to prevent erosion. Look at all feasible ways to cover the soil: in-row tillage, agroforestry, and alley cropping, growing combinations of crops that cover the soil surface well while maintaining high soil fertility.

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Figure 6-1. On steep slopes, cover such as grass, trees, and other plants is vital to keeping the soil.

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How to Keep and Increase Soil Fertility on a Steep Slope

Maintaining and enhancing soil fertility is urgent. Keep soil fertility high to produce healthy crops that cover the soil, build up organic matter, and increase yields.

- Return crop litter to the soil for mulch and compost. Use crop residues instead of burning them.
- Use green manure cover crops to the maximum. This is the cheapest, most efficient way to mulch and fertilize the soil. Adapt the appropriate legume green manure crop into the row crop program (the poor farmer's nitrogen fertilizer factory).
- Plant multi-purpose leguminous trees and bushes.
- Hoard animal manure until crop planting time, or use it to help make high quality compost.
- Use a lot of compost and animal manure.
- Urge farmers to have their soils tested where testing is available. They should add recommended amounts of commercial fertilizers, if available, and if the cost is in line with the selling price of the farm products.
- Since grass and legume tree vegetation will be growing to control erosion (live barriers), use a lot of it to feed additional livestock, as well as for green manure and mulch.
- Plan carefully for more in the farm program for fruit, nuts, firewood, and market.
- Plant fenced vegetable gardens for family use and for market.
- Increase the numbers and types of animals on the farm, where feasible.

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Figure 6-2. In-row Tillage Increases Soil Fertility

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Note: This soybean crop is off to a great start with high organic matter, no-till residue from last year's corn, and adequate moisture.

Diversified Farming Systems for Steep Slopes

In addition to utilizing conservation and soil fertility enhancement methods of all suitable kinds, the farmers should diversify the farming enterprises. In other words, they should combine various kinds of food crops, tree products, and animal products in their farming operations. A combined package of the best management practices plus specific crop and enterprise planning can lead to a productive sustainable farm system and a better quality of life. A diversified program can augment income and provide a hedge against disaster.

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How to Help a Farmer Strategize for Diversified Farming

1. Make preliminary evaluations. Analyze with the farmers, their neighbors, and village leaders the needs, in addition to the many problems and possible solutions that the farmers, the community, and you see. What needs and problems do the farmers themselves perceive? Their input is vital to successful implementation.
2. Seek counsel. Supplement with discussions with your PCV friends, specialists, if available, and government researchers and specialists. What are the possibilities for this particular location and situation? How can the farmer achieve a satisfactory, sustainable way of life? There are usually many possibilities.
3. Consider and analyze various opportunities. Besides the usual food crops, what other kinds of food or products can be produced? What are their potentials for local markets? For distant markets? How could the farmer transport the products? If the community is in the mountains, what cool season crops could be grown? Many foods or products, which do not do well at sea level, will grow in the high cool elevations of the tropics. They are often in demand at markets in the lower elevations. Such products include cabbage, certain kinds of peas, broccoli, berries, etc.
4. Investigate using irrigation. This may be possible in the mountains during the dry season. You may find a small, ever-flowing stream or a big spring located some distance above a farmer's field.

A large open delivery ditch may result in the loss of too much water if the volume of water is small and it is transported very far. Some possible ways to handle and use the water are:

- One or more farmers can bring the water down in a small plastic pipe. Water brought down through a pipe may produce enough pressure to operate an irrigation sprinkler. If not, some type of drip irrigation may help conserve water.
- In some cases farmers have used homemade bamboo pipes to convey water a considerable distance. These pipes can be used for either drip irrigation or narrow row irrigation.
- Will a hydraulic ram work for your situation? If you find a stream flowing on a relatively steep slope below a farm, you may want to help build a very inexpensive or water-powered hydraulic pump, to lift the water up the hillside. When properly constructed, the water ram will force a considerable amount of the stream up to the farm. Given a good-sized stream with a fairly steep slope (to build up a strong "head" of pressure), it can supply enough water for small-scale row irrigation or drip irrigation. It can also provide water year-round for family and for farm animals, a major consideration if water has to be carried up the hill. (Check with other PCVs and contact the Peace Corps library for plans. A local plumber or mechanic, if available, could help you follow the plans.)

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Animals as Part of Soil Conservation on Slopes

Ruminant Animals

Ruminants have a special extra stomach containing organisms that break down tough materials like cellulose. Therefore, they can be healthy by eating nothing but grasses, tree leaves, and hay.

Ruminants such as cows, goats, and sheep are grazers of grasses and feeders of leaves, stems, and tender twigs from shrubs and trees. Therefore, these animals are especially suitable for steep slopes.

However, ruminants and other animals can destroy gardens, crops, terraces, green barriers, and seedlings if allowed to roam loose. Small farmers are wise to pen their animals and to cut and carry feed to them. As an added advantage, all of the valuable manure fertilizer (for compost, gardening, or crops) will then accumulate in an enclosed area. (Note: Always keep the manure pile protected from sunshine and rain.)

If ruminant animals run loose, the farmer needs to devise some scheme to protect his or her crops, including small trees, from destruction.

Useful Ruminants for Farmers to Consider:

- Milk goats provide sources of milk and cheese for the family or to sell occasional meat. Contact Heifer Project International for an excellent manual on raising goats and for instructions for making cheese and other dairy products.
- Milk cows provide milk for the family, as well as milk butter and cheese to sell.
- Sheep provide a possible source of milk and cheese; food; wool for sale; and wool to weave into clothing for the family or to market. (Example: Indian fabric and garments made in the mountains of Central and South America.)
- Oxen or water buffalo are powerful for pulling plows, carts, wagons, or for carrying goods.

Non-ruminant Animals

Useful non-ruminants to consider include:

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Rabbits and Guinea Pigs

These are not ruminants but they can eat many of the same foods. They do need a small amount of energy food (table scraps, root crops, or grains), but mostly green leaves and hay. They are usually easy to care for and reproduce well. The animals are small and easy to handle.

Rabbits and guinea pigs are relatively inexpensive to raise. The farmer can build raised cages out of bamboo or small tree branches at no cost. The farmer can secure two or three females and a buck for very little, and produce a prodigious amount of protein.

Although using rabbits and guinea pigs as food repels some people, both supply excellent meat. Rabbit meat is also extremely low in cholesterol. Usually the market for rabbits (and sometimes for guinea pigs) is easy to develop. They can be sold to restaurants or used as family food. People who enjoy chicken, which has a similar flavor, adapt readily to eating rabbit or guinea pig if a local cook prepares them an introductory meal by traditional methods of cooking chicken.

Rabbit hides can be tanned and sold in the market, or turned into purses, rugs, and clothing. The manure is an excellent fertilizer.

Fowl

Fowl are not only chickens, but also ducks, geese, turkeys, etc. They are sources of meat, eggs, feathers, and manure. Many fowl can find insects, wild seeds, and weeds to supplement their diets. However, they must be fenced out of the family garden.

The manure from fowl contains two times more nitrogen fertilizer than most other manures. Caution: When using fresh manure, mix it thoroughly with the soil. Do not expose the roots directly to it or the raw manure may burn the plants.

Bees

Raising bees and selling honey can be an excellent additional income enterprise for hill farmers, especially where trees and bushes with nectar (or other nectar-producing crops or weeds) grow.

Beekeeping can be handed down from parent to child—an ideal family enterprise. The bees can be kept in the homestead near the farmhouse, or scattered throughout several locations on the property of friends or relatives.

Bees are sometimes especially important to maximize pollination of fruit trees or certain field crops grown for seed.

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Animals for Transportation and Burden-bearing

A horse, donkey, ox, or mule can be important to some mountain families who are isolated or live long distances away from markets. The manure is also very valuable. These may include specific local types, such as llamas.

Precautions

If you plan to help raise animals, be sure to secure good practical instruction manuals. Check Peace Corps publications at your local Peace Corps office. Consider writing to Heifer Project International, a private charitable group specializing in animals, for booklets and help on special problems.

Special conditions, such as local animal insects or diseases, can raise havoc. However, local animals often already have resistance to them.

Sometimes crossbreeding with imported breeds can improve production while retaining local breeds' resistance to disease.

Know local sources of veterinary help.

Ways to Develop Additional Markets for Animals

In addition to the regular traditional type of market, investigate other sources. What local restaurants could buy rabbits to serve their clientele? What local stores might have a deep freeze and carry frozen rabbits or chickens? What store might stock fresh cow or goat milk? Yogurt? Local cheese? Honey? Can local cooks sell grilled chicken or rabbits at small roadside stands?

A Private Voluntary Organization (PVO) or other organization might help, especially after farmers form a small cooperative. The PVO registration program connects USAID with new and capable Non-Governmental Organization (NGO) partners that provide lasting solutions to development, humanitarian, and health challenges.

The SALT System³

The Asian Rural Life Development Foundation (ARLDF) in Kinuskusan, Bansalan, Davao del Sur, Philippines, promotes an erosion control technique that is both easier and less expensive to implement than traditional methods. This technology is known as SALT, or

3 Much of the content on SALT is adapted from ARLDF Editorial Staff, "How To Farm Your Hilly Land Without Losing Your Soil." ARLDF, Kinuskusan, Bansalan, Davao del Sur. 1997 Edition. 20. How To Series No. 1. Available online at <http://www2.mozcom.com/~mbrlc/salt1/cover.html>

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Sloping Agricultural Land Technology. The technology has also worked well for individual small farmers throughout the Philippines and in other tropical countries. It is now known worldwide.

SALT is a package technology on soil conservation and food production, integrating different soil conservation measures in just one setting. For SALT to be successful, an appropriate nitrogen-fixing tree or shrub must be used—one that grows well and resists drought, diseases, and insects. Also, the farmer should have secure land tenure. SALT is an outstanding demonstration of a “live barrier” complete erosion control system. It is a successful agroforestry steep slope farming system. It uses the basic idea of alley cropping, but modifies it into a unique farming system.

Setting up the SALT System on Farms

SALT combines various soil conservation methods and agroforestry with food production at a particular location. This method grows field and permanent crops in 3 to 5-meter bands between rows of nitrogen-fixing trees. The trees are planted thickly in double rows on the contour. When the tree hedge is 12 to 18 months old and reaches a height of 2 meters or more, the trees are cut back to a height of about 40 centimeters. The clippings are spread in alleyways to become mulch and organic fertilizer. Like alley cropping done in Africa, the legume trees are allowed to grow in the dry season, but are cut back when the crops are planted or when the hedge competes with the food crop.

A typical SALT farm is set up like this:

- Permanent shrubs or trees like coffee, cacao, citrus, and other fruit trees are planted in some of the strips between the legume tree hedgerows.
- Other strips, alternately planted, include cereals (corn, upland rice, sorghum, etc.) or other crops (sweet potato, melon, pineapple, castor bean, etc.). This cyclical cropping gives the farmer some crop yields throughout the year. At the same time, the live legume tree barriers minimize water runoff and soil erosion.
- The system also includes planting trees for timber and firewood on top of the hill and surrounding boundaries. Tree species for “boundary forestry” in SALT include mahoganies, casuarinas, sesbanias, cashew nuts, pili nuts, etc. Such species may not be applicable to your location, but the SALT method can be adapted effectively to local varieties in your area.

Basic Requirements that the SALT System Meets

The people designing the SALT program in Mindinao felt that the following guidelines had to be met:

- The method must adequately control soil erosion.

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- It must help rebuild soil structure and fertility.
- It must be efficient as a food crop production system.
- It must apply and be helpful to at least 50 percent of hillside farms.
- Upland farmers must be able to duplicate it easily using local resources and preferably without borrowing money.
- Minimum labor must be required.
- The method must be culturally acceptable.
- The farmer will be the chief focus and producing food will be the main priority.
- The system must be workable in a relatively short time and be economically feasible.

Most of these criteria are necessary in any transfer of SALT technology to your location, if this method is to succeed. (For that matter, any technology transfer for any project with the small tropical farmer must meet most of these criteria. They are fundamental considerations.)

Advantages of the SALT Method

- It is simple and low in cost.
- Easy to apply: A farmer needs few tools, little money, and minimum knowledge of farming. It employs “appropriate technology.”
- The farmer can grow crop varieties he or she is familiar with.
- The farmer can use old farming methods he or she is familiar with.
- If the farmers abandon the land, the trees serve as a deterrent to soil erosion, and any nitrogen fixing trees or shrubs continue to nourish the soil. Clippings from the trees can also still be harvested for firewood, charcoal, compost, feed, poles, etc.

Different Forms of the SALT Method

There are several forms of SALT and a farmer may wish to use the SALT system in several variations. Simple Agro-Livestock Land Technology (SALT 2), Sustainable Agroforest Land Technology (SALT 3), and Small Agrofruit Livelihood Technology (SALT 4) are three variations of SALT that have been developed at Mindanao Baptist Rural Life Center in the southern Philippines.

How to Install the SALT Method—Ten Steps

1. Make an A-frame

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You can make an A-frame using material from the farm. You will need three strong wooden or bamboo poles; something to saw or cut with; a carpenter's level; and some string, rope, or nails.

Make the legs of the A-frame by cutting two pieces of wood to a length of 1 meter. A third piece of wood, which will serve as the cross bar, should be cut at least 1.5 meters long.

To put the A-frame together: Tie together the upper ends of poles that are 2 meters long. Stand the lower ends on level ground. Spread them to form a good angle (about 1 meter apart). Use the shorter pole as a horizontal brace. Fasten the carpenter's level on top of the cross bar by tying it. Be sure that the instrument reads level on level ground.

You will use the A-frame to find the contour lines.

2. Locate the Contour Lines

A contour line is an imaginary level line or level pathway around a hillside or along a mountainside.

Remove anything that will keep you from moving about freely and marking lines (tall grass, obstructions, etc.). If possible, use two people—one to work the A-frame and one to mark the contour lines with stakes.

Begin marking the contour lines near the highest point of the area. Stand the A-frame on the ground. Raise the front leg while the rear leg remains on the ground. Place the front leg on ground that is on the same level as the rear leg. You will know the legs are on the same level when the bubble in the carpenter's level stays in the middle. You now have a level line between the two legs of the A-frame. This is a contour line between them. Use a stake to mark where the rear leg stands.

Try to locate as many contour lines as possible. Remember, the closer the contour lines to each other, the more potential erosion control occurs. Also, more nutrient rich biomass is produced and made available to the crops growing in the alley.

There are two criteria for determining the distance between contour lines: vertical drop and surface distance. Generally, no more than a 1-meter vertical drop is desirable for effective erosion control. Therefore, the steeper the slope, the closer the contour hedgerows. Conversely, the flatter the slope, the wider the spacing of hedges. However, on the flatter slopes, it is recommended that contour hedgerows be spaced no farther apart than 5 meters in order to maximize the benefits of the nitrogen fixing trees/shrubs on soil fertility management.

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In determining a 1-meter vertical drop, the “eye-hand” method is a simple procedure to use. If using a transit or homemade transit, the 1-meter vertical drop can be obtained very quickly.

3. Prepare the Contour Lines

After you have found and marked the contour lines, prepare them by plowing and harrowing until ready for planting. The width of each area to be prepared should be 1 meter. The stakes will serve as your guide during plowing.

4. Plant Seeds of Nitrogen-fixing Trees and Shrubs

On each prepared contour line, make two furrows 0.5 meter apart. Sow the seeds in each furrow to allow for a good, thick stand of seedlings. Cover the seeds lightly and firmly with the soil.

The ability of nitrogen-fixing trees to grow on poor soils and in areas with long dry seasons makes them good plants for restoring forest cover to watersheds, slopes, and other lands that have been denuded of trees. They enrich and fertilize the soil through natural leaf drop. In addition, they compete vigorously with coarse grasses, a common feature of many degraded areas that have been deforested or depleted by excessive agriculture.

Flemingia macrophylla, *Desmodium rensonii*, *Gliricidia sepium*, and *Calliandra calothyrsus* are the best examples of nitrogen-fixing trees for hedgerows on the SALT farm. Other examples of nitrogen-fixing trees and shrubs (NFTS) that may be suitable for SALT hedgerows are *Indigofera tyesmane*, *Calliandra tetragona*, *Leucaena luecocephala*, and *Leucaena diversifolia*. The members of the *Cassia* genus, such as *spectabilis* and *siamea*, are not mentioned here because of their doubtful fixing on nitrogen. Remember, you must select the species that grows best, based on your climate and particular soils.

5. Cultivate Alternate Strips

The space of land between the thick rows of nitrogen-fixing trees where the crops are planted is called a strip. Other names for the strip are alleyways or avenues.

If you wish to prepare the soil for planting before the NFTS are fully grown, do it alternately on strips 2,4,6,8, etc. Alternate cultivation will prevent erosion because the unplowed strips will hold the soil in place. When the NFTS are fully grown, you can proceed with cultivation on every strip.

6. Plant Permanent Crops

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Plant permanent crops in every third strip. They may be planted at the same time the seeds of nitrogen-fixing trees are sown. Only the spots for planting are cleared and dug; later, only ring weeding is employed until the NFTS are large enough to hold the soil so full cultivation can begin.

Durian, lanzones, rambutan, coffee, banana, citrus, cacao, and others of the same height are good examples of permanent crops. Tall crops are planted at the bottom of the hill while the short ones are planted at the top. Shade-tolerant permanent crops can be intercropped with the tall crops.

7. Plant Short-term Crops

Between the strips of permanent crops, you can raise crops that can produce income and food while you are waiting for the permanent crops to yield. These can produce short- or medium-term income or both.

Plant tall crops away from short ones to prevent shading. Some possible short- or medium-term crops might be corn, sorghum, upland rice, melon, mung bean, peanut, pineapple, camote, ginger, castor bean, and gabi.

8. Trim Nitrogen-fixing Trees

Cut these trees down once a month to about 1 to 1.5 meters tall. Pile the leaves and twigs around crops to serve as good fertilizer. This will reduce the need for chemical fertilizer to about one-fourth of the total requirement.

9. Practice Crop Rotation

Rotate crops that are not permanent in order to maintain good soil condition and fertility. A good way of rotating is to plant grains (corn, upland rice, sorghum, etc.), root crops (camote, cassava, gabi, etc.) where legumes (mung bean, bush sitao, peanut, etc.) were planted previously and vice versa. In your area, other crops may, of course, be useful or better adapted.

You will want to follow such good practices as weeding and control of insects and pests.

10. Build Green Terraces

Dense double rows of nitrogen-fixing trees are already helping control erosion. Natural terraces are also developing along the contour lines of the hill. Regularly gather and heap up straw, stalks, twigs, branches, leaves, rocks, and stones at the base of the rows of nitrogen-fixing trees. This helps build strong, permanent, naturally green, and beautiful terraces.

Introduction

Soil erosion by wind occurs when wind dislodges soil particles and moves them to another location. Wind erosion will take place when wind with velocity of about 20 kilometers per hour or more blows over very dry, loose, poorly structured soil.

Wind erosion can be very serious in regions of fairly level and frequently dry soil (low rainfall from 250–500 millimeters) and significant wind velocity. Under these conditions, huge amounts of valuable topsoil can be removed from a farm in a day or two.

Wind-borne soil moves sand and silt onto neighboring land or even considerable distances away, sometimes destroying both the land it came from and where it goes. It covers roads and railroad tracks.

Dust storms can vacuum up fine soil particles and organic matter a kilometer or more into the air, transport them 800 kilometers or more, and deposit them as fine particle dust. The wind picks up and transports the finest lightest soil: the clays, silts, and organic matter. Since clays, silts, and organic matter hold most of the plant nutrients, the larger soil particles that are left will be much less fertile.

Wind erosion can produce heavy loss of soil fertility over wide areas of land. The ultimate long-term result can be desertification. Wind erosion now destroys millions of hectares of land each year. Both wind and water erosion are denuding land at an alarming rate.

This chapter outlines the mechanics and factors affecting wind erosion and how to fight it.

Role of Farmers and Wind Erosion

Except in natural deserts, wind erosion did not seriously threaten land before man began to cut forests and to plow fragile areas that should have been left undisturbed. As man moved in, the picture changed.

During the 1930s, the “dust bowl years” in the United States, wind erosion devastated farms in the high plains. You have seen pictures of the “dust bowl” in which clouds of blowing dust darkened the skies for hundreds of miles.

The winds severely eroded millions of acres once covered by a carpet of sod and grazed by wild animal herds. The Grapes of Wrath tells a tragic story of a typical farm family, destitute and hungry, leaving the dust bowl in search of work. There were thousands of such families.

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The tragedy of the 1930s occurred because farmers had plowed the natural grassland of this semi-arid region—land that should not have been plowed. They farmed the land year after year without proper conservation methods. Gradually, cultivating crops used up the organic matter, destroying the soil structure. Following several years of drought, the dry topsoil blew away.

In many other parts of the world today, men and women are still making similar mistakes. Farmers plow up land that should not be plowed. In some places, animals are overgrazing grasslands and brush lands, leaving the soil bare. By trampling the land with their hooves, especially areas surrounding watering holes, animals compact the topsoil, destroying the soil structure and creating the conditions for wind erosion.

Where Does Wind Erosion Occur?

The most far-reaching problems occur in the Great Plains of the United States and Canada, and the Sahara and Kalahari deserts in Africa, Central Asia (the steppes of Russia), and Central Australia. However, wind erosion also occurs elsewhere, particularly in other arid and semi-arid regions (300–500 millimeters rainfall).

Under What Conditions Does Wind Erosion Occur?

Soil erosion by the wind can occur where dry bare soil is exposed to prevailing winds of significant velocity (20 kilometers an hour or more). Arid and semi-arid areas are particularly vulnerable. Wind erosion is most serious in areas prone to dry soil, especially if the land is level, preventing the terrain from obstructing the force of the wind.

Wind force does not move wet soil. However, this does not mean that humid areas are necessarily free of wind erosion. Lands that experience heavy rainfall and erosion from raindrop splash during wet periods can suffer from wind erosion during dry periods.

Erosion by wind can occur in special situations in humid areas. For example, during droughts, winds in Ontario, Canada erode the land in the farming areas between Lake Ontario, Lake Erie, and Lake Huron, and also in the Coastal Plains of the southeastern United States. In other humid areas, winds carry away soil from peat land if the soil has been plowed and left bare (thus it is too dry).

You can find some soil being eroded anywhere dry soil is exposed to too much wind. Silty-sandy soils with very poor structure are the most vulnerable.

Mechanics of Wind Erosion

The mechanics of the movement of soils by wind were first understood from the work of two pioneer researchers in the early 1940s: Bagnold (working in Great Britain and North Africa) and Chepil (working in Saskatchewan, Canada and Kansas in the United States). They found that wind forces move soil through the following three processes.

Suspension

The wind vacuums up small, fine particles of clay, silt, and organic matter (particles that are less than 0.1 millimeters in diameter). It holds them in suspensions at heights of thousands of meters, to be transported long distances.

One study found that a strong dust storm, originating in 1937 in west Texas, deposited its suspended dust load in central Iowa. The dust was left on top of a deep crust of snow in Iowa where it could be measured. The snow kept the deposited dust from coming in contact with the soil beneath the snowbank, making accurate analysis possible. The storm blew away most of the fertility from the west Texas field. It removed two-thirds of the nitrogen and organic matter, along with much phosphorus and potassium. It also removed about 37 percent of the very finest clay particles. The soil structure in Texas had to be very poor for such serious erosion to happen.

Saltation

Soil particles with diameters from 0.05 to 0.5 millimeters can be transported by saltation—moved along by the wind a few millimeters at a time, bouncing and rolling. Most of the transported particles are medium size and fall in the range of 0.1 to 0.15 millimeters in diameter. The name “saltation” comes from the name of a similar process whereby sand particles are moved by the force of water bouncing along the sandy bottom (bed) of a stream.

When small sand grains blow along the surface of the topsoil at a rapid rate, some of them will bounce almost vertically into the air. The medium sand particles affected by this energy often rise 30 centimeters or more, but not above 1 meter. Those that bounce up to 30 centimeters high will encounter considerable wind force blowing horizontally. Pushed by the strong lateral force of the wind, plus the pull of gravity, they fall back to the earth at various acute angles. The effect will be similar to cutting with a knife at an angle or to sandblasting.

Many of the grains will land with great force at sharp angles (10 degrees or less). The strong cutting and scooping force tosses more grains vertically. These sand grains will also rebound strongly at acute angles when returning to the surface. In turn, they bounce, increasing numbers of grains. The process builds upon itself in an intensifying and accelerating system that can move huge amounts of particles in a short time.

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In addition, saltation loosens smaller particles, freeing them to be sucked up and suspended easily by vertical air streams.

Surface Creep

The larger particles (usually from 0.5 to 2 millimeters) are too heavy to be lifted into the air and will roll along the surface after being hit by the particles in saltation.

The bouncing grains from saltation strike them, nudge them, and push them along with help from the wind force. The word “creep” describes the process very well! As long as the wind blows, these larger particles will keep moving until they encounter an impediment, such as a fence, vegetation, etc. These larger particles cover less distance and move more slowly than the medium ones moved by saltation.

Amounts of Soil Moved by the Wind Processes

Of the three processes, saltation moves the most soil. Estimates of the amount of soil moved by saltation range from 55–70 percent of the total amount eroded by wind. Suspension apparently removes from 3–38 percent. Amounts of soil removed by creep range from 7–25 percent. Most of the soil movement by wind takes place immediately above the soil surface. Fifty percent occurs within the first 5 centimeters above the soil surface and as much as 90 percent within 30 centimeters of the surface.

So, any 30 centimeters-high obstruction will stop most saltation and creep. However, to stop suspension and crop damage from wind, the obstruction must be higher or placed very closely together.

Wind tunnel experiments suggest that 150 tons per hectare per hour can be moved from a field when a 40 kilometers per hour (24 mph) wind is blowing. Most of this would be from saltation. Some observers in the field report that strong windstorms can move more than 100 tons of soil per hectare in an hour. As stated earlier, an acceptable guide for the farmer, depending on his or her circumstances, might be the loss of no more than 11 or 12 tons of soil per hectare per year from any cause.

Factors Affecting Wind Erosion

Wind Velocity

The higher the velocity, the more soil is moved. When wind speed increases, its destructive ability becomes proportional to the square of the velocity of the wind.

For example, let us assume that a shelterbelt of trees reduces the wind speed 40 percent at a distance of 25 meters downwind from the tree belt. A 60 kilometers per hour (37 mph) wind blowing over the field before reaching the trees would have a destructive force of 60² or 3,600 units. Twenty-five meters beyond the trees (on the lee side), the speed would only be 40 percent x 60 = 24 kilometers per hour. Here, the fraction would be:

$$\frac{(24)^2}{(60)^2} = \frac{576}{3600} = 16 \text{ percent}$$

The destructive force is therefore reduced by 84 percent at a distance of 25 meters from the tree belt. This simple calculation indicates the importance of taking measures to slow down the wind. Good windbreaks greatly reduce wind speeds on the lee side of the barriers, for a horizontal distance of four to six times the height of the barrier.

Soil Texture—Soil Structure

Sandy-silty soils are more susceptible to wind erosion than clay soils. Fine sandy soils with low organic matter content and poor structure are highly vulnerable to the wind.

Smoothness of Soil Surface

A seedbed of finely prepared soil encourages wind erosion. A very rough soil surface can help control wind erosion.

Dryness of Soil

Certain very dry soils blow easily. Moist soils do not blow.

Amount of Vegetative Cover on the Soil

The more vegetative cover on the soil, the less erosion occurs. Also, plant root helps anchor the soil.

How to Fight Wind Erosion?

Follow Good Land-use Methods

Proper use of the land is the best way to prevent wind erosion. Many sandy-silty soils with poor structure that are already growing good grass should remain in grass and shrubs. Usually the grass should not be plowed under for row crops. This means using the land for grazing.

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To keep the grass cover from dying out, do not overgraze. Move the cows, oxen, goats, and/or sheep often enough for the grass to regrow. Rotate the grazed areas.

Where poorly structured land must be plowed for the family to have food, emphasize using many of the good land practices discussed below to prevent wind from blowing the loose soil and also damaging the crops.

Develop and Keep Good Soil Structure in the Topsoil

Do not burn the post-harvest trash, such as stalks, leaves, and stems. Leave it all to be turned under. Or turn part of it under, and leave part on the surface as mulch. This will help protect from wind blowing the soil surface and will add organic matter to improve the soil structure.

Rotate crops so that legume crops grow in the soil every 2 or 3 years. Legumes improve soil structure and produce nitrogen. Depending on rainfall and other climatic factors, certain types of legumes will do better than others.

Use plenty of animal manure, compost, and some commercial fertilizers for healthier plants, more crop yield, and more organic matter.

Keep the soil moisture high when possible, especially during high winds.

Leave a Rough Surface on the Field when Plowing and Where Crops are not Present

When plowing fields, leave some crop residue on top of the soil.

Run the rows and strips perpendicular to the prevailing wind (assuming that erosion from water is not occurring). If the farmer plows the furrows perpendicular to the wind, the ridges on the sides of the furrows will offer some wind resistance.

The rougher the soil surface is due to clods and trash, the less vulnerable it is to the wind. If possible, plow deeply enough to bring up large clods of dirt from below.

Leave the surface unbroken or rough. Do not harrow or pulverize the soil. Do not prepare extensive, finely textured seedbeds.

Plow some strips in the field later than others so that some unplowed strips remain with crop stubble still in place.

If the soil is heavy and drainage is a problem, use a blower that forms ridges when it plows. Put the ridges on the contour if the land is rolling. If the land is level, run the ridges and rows

perpendicular to prevailing winds. Mix trash into the soil, or leave as much crop residue as possible on top of the ridges. Plant crops on top of the ridge.

Keep Live or Dead Vegetative Cover on the Soil During the Windy Season

Keep some type of crop cover, stubble, or mulch on the land, especially during those critical months when winds are frequent and strong. When possible, avoid plowing up large areas of sod or other vegetation. Cultivate in strips, leaving some untilled.

Do not gather crop post-harvest trash for feed or fuel. Leave it in the field. (Investigate other solutions for feed and fuel needs.)

When plowing the field or when cultivating or weeding with a hand hoe, leave the dead plant material on the soil surface (unless it is a noxious weed.)

If the field is to lie fallow, control the weeds to preserve soil moisture.

At plowing time, consider using tools to cut the weeds and the soil surface and loosen the soil under the surface without turning it over. The cut stubble stays on the soil surface. This is called field-trash farming.

Plant the crops through the mulch, leaving the soil protected. The limited rainfall penetrates the soil more quickly; the mulch protects the soil from wind, reduces moisture evaporation, and lowers soil temperature.

When harvesting grain or other food crops, leave either the long stubble or the whole plant standing in the field. They have resistance to wind.

Where firewood or fodder is scarce, the farmer may need to plan in advance and plant trees specifically for fodder and firewood. Plant in a manner that will provide wind protection.

Use a strip crop rotation system. In strip cropping, grow crops in strips planted to different crops, with 5 to 15 meters wide strips. Usually the farmer alternates strips of two to three different crops. Ordinarily, run the strips of crops perpendicular to the wind direction. Caution: Where water erosion also occurs, put the strip on a contour. One or more of the crops might be a variety that would serve as a cover crop during a strong windy season. This could be planted in every other strip if only two crops are planted, or every third strip if three crops are planted. Depending on what crops grow well, plant one tall crop in the rotation. (Tall crops act as “micro-windbreaks.”) Wind speed is greatly reduced for a horizontal distance of six plant heights on the lee side. The tall crops, therefore, can protect the adjacent strips of low-growing crops or of plowed soil downwind. In some areas, sorghum and pigeon peas are

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useful tall crops to plant in strips (Note: Pigeon peas are also legumes). If a sorghum plant is 2 meters tall, the soil downwind from it can have good protection for up to 12 meters.

If the farmers need livestock feed, consider growing grass-legume strips for 2 or 3 years. Grass (together with a legume) could grow in one strip, then tall crops in one strip, and a low food crop in another strip, etc. Consider growing a nitrogen fixing-multiple purpose tree or shrub strip for feed and demonstrating a windbreak. (See the section below.)

Practice Water Conservation

The farmer should practice good soil and water conservation methods on all rolling lands. Some soils are endangered by raindrop splash erosion, as well as wind erosion. Also, capturing rainwater and conserving soil moisture is particularly important in arid and semi-arid regions. Keep as much moisture as possible for crop growth in the topsoil. Another benefit is that moist soils do not blow.

Use Windbreaks

Choose Suitable Tree Species

Mature trees make wonderful windbreaks. However, many varieties will not be feasible for very low rainfall areas. Check with your local agricultural specialists and farmers about the seriousness of wind erosion in the area and recommended tree species. Ask whether there are farmers who are already using tree barriers (shelterbelts or windbreaks).

Consider *Albizia lebbbeck*, *Cajanus cajan*, and *Chamaecytisus palmensis*. All three are recommended for erosion control, alley farming, and green manure in arid and semi-arid climates. Lebbbeck and palmensis produce nectar for honeybees. Cajan provides human food. Lebbbeck produces rough lumber. Cajan and palmensis are recommended for growing to maturity for windbreaks, if needed. Also see a list of suitable trees at the end of Chapter 5. See Chapters 4 and 5 for instructions for planting and caring for trees.

Consider Multipurpose Trees and Alley Cropping

A combination windbreak-agroforestry approach with multipurpose trees can be helpful. The need for fodder is the most serious constraint to raising animals in arid and semi-arid lands. Firewood is another major concern. Certain trees can provide both.

In many areas, appropriate trees can fit into some type of modified alley cropping or other type tree and food crop farming system. The rows of trees will need to be widely spaced to avoid competition with food crops for moisture, but they can also act as windbreaks and, of

course, provide desperately needed fodder and firewood. If the land is flat, the rows should be planted perpendicular to the prevailing winds.

Agroforestry researchers are now very busy testing tree varieties and studying farm systems for drier areas. There are real benefits for the farmer who plants more trees. Contact the Nitrogen-Fixing Tree Association for trees recommended for your area.

Although windbreaks often work well, some of the land will blow in spite of them if the soil does not have good structure. Many farmers can best control wind erosion by careful land husbandry (good farm management). This will also help increase the crop yields.

Farmers must maintain an adequate organic matter level in the topsoil in order to keep and build good soil structure. They should not denude the fields of crop stalks and leaves, not even for livestock feed or cooking fire. This will be possible only if other farm planning provides for these serious needs by growing some trees specifically for these purposes.

Fortunately, well-chosen varieties of trees or shrubs in windbreaks can help. Finding the right fast-growing multipurpose trees and starting some demonstrations is a first step. These trees might be planted in a block for fuel or feed, or as windbreaks, or as some type of special widely spaced alley cropping. In any case, the trees would furnish badly needed feed for livestock and firewood so that crop residue could be left in the field.

Where possible, natural grasses and vegetation (but not serious weed pests) should be allowed to re-cover unused areas. The rules for covering the soil emphasized throughout this manual equally apply to wind erosion. They are, however, hard to carry out successfully in the drier zones.

Benefits of Growing Windbreaks

Windbreaks in fields (rows of trees, shrubs, tall grasses, or other tall crops used to reduce wind speed) offer the following benefits:

- Soil erosion is greatly reduced.
- Young plants are protected from blowing sand.
- With proper management, food crop yields increase noticeably.
- Efficient use of soil moisture increases because evaporation of moisture by wind from the soil is reduced, leaving more water for the food crop.
- Quality of the food crops improves noticeably.
- Stems and leaves harvested from tree windbreaks make good mulch and compost.
- Trees also supply fuel, food, and fodder.

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Windbreaks for farmsteads (used to protect the home, barns, gardens, orchards, people, and animals) offer:

- Protection from strong wind and sandstorms for people and animals
- More day-to-day comfort, health, and well-being
- Protection of buildings and equipment
- Protection of the water supply
- Better quality and higher yields from the garden and orchard
- Useable byproducts (e.g., nuts, fruits, firewood, fodder, food, and lumber) for family use and for sale

Experience from Egypt

Egypt has some of the oldest continuously farmed land. Hot, dry winds buffet Egyptian soils in late spring and summer, as do sandstorms.

The network of windbreaks in Egypt is one of the most extensive in the world. Forestry and agriculture are commonly integrated on farms, with most of the trees planted in windbreaks. Trees used for windbreaks are usually varieties of *Eucalyptus*. *Casuarin Eucalyptus camaldulensis* comprises 20 percent and *Casuarina equisetifolia* over 70 percent of the windbreaks in Egypt. For special problems like saline soils and waterlogged conditions, or where brackish water is used for irrigation, farmers plant *C. glauca*.

Handling Problems in Establishing Windbreaks and Shelterbelts

Experienced field workers all say the main problems in establishing windbreaks stem from a lack of farmers' understanding and interest, and lack of care of seedlings after they are transplanted. The tender plants need water from time to time, weeding, and protection from grazing animals.

The most effective teachers for farmers have consistently proven to be other farmers who have successfully established windbreaks on their own farms and have benefited from farmer demonstrations. Farmer field "know-how" serves as the best classroom and provides the best teachers.

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Appendix 1: Basic Tool Kit of Techniques for the Field

How to Make a Simple Rain Gauge

Certain commercially made devices measure rainfall by intensity and amount—namely a recording rain gauge or the (less sophisticated) standard rain gauge. You are in luck if either is available to you. They probably will not be. Even if they are available, farmers will need less expensive ways to measure rainfall at more than one location. You can teach them to make a satisfactory rain gauge from a straight-sided round metal can.

You may want to have several farmers make simple gauges and measure the depth of water in millimeters with a stick — and keep careful records. These records will be invaluable! This is also an excellent way to teach farmers about rainfall, raindrop splash erosion, and the importance of careful record keeping.

1. Locate a watertight can that is open at one end. It should have a diameter of 5 to 10 centimeters and should be 25 centimeters or more tall. The sides should be straight, not tapered, in order to ensure fairly accurate measurement.
2. Mount the can on top of a building or a post, away from the reach of children and animals.
3. Mount it so that it is level.
4. The can should be in the open, away from buildings or trees that could interfere with its ability to catch an accurate sample of the rainfall. It should be at least one height away. That is, it should be at least 10 meters away from an obstruction that is 10 meters tall, or 30 meters away from a tree that is 30 meters tall.
5. Mount the can so it can be emptied each time after the farmer reads and records the rainfall.
6. Be sure the can is secured well enough with wire or string so it will not blow away during a high wind.
7. Make a stick ruler to measure the water depth in the can. Put some notches, as well as written indicators, on the ruler. The measurement will give you the amount of rain that has fallen (in centimeters or inches—however you marked the ruler). Depending on the needs, rainfall can be measured after a particular rain, or for 24 hours. If records are made during a season of continuing rain, record at the same definite time each day.
8. A glass or plastic container is ideal. You can mark it and measure the water quickly by sight through the glass to gauge intensities during a rainstorm. Remember that high-intensity rains have more large raindrops and do maximum damage to soil surface. Rainfall of 4 millimeters per hour does no damage, but that of 50 millimeters can cause much erosion.
9. Keep accurate data. After each rain, record the date, time, and amount of rainfall and peak intensity, if possible, in a sturdy notebook.

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How to Measure Steepness of Slope

As steepness of slope increases, the force of runoff water increases. Therefore, the contour ditches and barriers must be closer to each other to control erosion. In addition, steepness of slope often changes at different places on the same hill, and the distances between contour ditches, barriers, etc. should vary accordingly.

Slope can be expressed as the degree the slope makes with the horizontal (i.e., a 90-degree slope is vertical; a 45-degree slope is halfway between the 0-degree slope [horizontal] and the vertical).

However, an easier way to express this is as “percent slope.” This is an expression of the vertical distance units (inches, centimeters, etc.) divided by the horizontal distance units x 10.

Formula: percent slope = the units of vertical drop or vertical elevation divided by the units of horizontal distance x 100.

Examples: A field with a 10-percent slope has a vertical drop of 10 meters for every 100 meters horizontal distance. Alternatively, if you are looking up the hillside, it has a 10-meter vertical rise for every 100 meters of horizontal distance. Similarly, a 30-percent slope would have 30 meters fall (or vertical rise) for every 100 meters measured on a horizontal line.

When you are measuring vertical distance, remember that the horizontal line must be level with the point of origin. In other words, to measure the true horizontal, the measuring tape, rod, or string must be held level when the vertical distance is measured at the end of the tape.

Examples: If the slope is 100 percent, it will drop down vertically, as in an elevator, for the same distance as the horizontal distance involved. This is often called a 1-to-1 slope, i.e., 1 unit down (or up) for every horizontal unit. A 20-percent slope would be a 1-to-5 slope, or a drop of 20 meters for every 100 meters horizontal. (A 100-percent slope makes a 45-degree angle with a level horizontal line.)

Using an Inclinator

The Abney level, or inclinometer, is a sight level. You hold the instrument to your eye as you focus on a distant target that another person holds. The target is the same vertical distance from the ground surface as your eye is. By rotating the instrument dial until the bubble indicator is level, you can read directly the percent slope or the degree of slope angle. You may find it useful for making quick, rough estimates.

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Using a Carpenter's Level

If you have access to a carpenter's level you can tie it to the top side of a board or rod that is 2 to 4 meters long. Place the board on the ground, pointing down the slope. Hold the upper end firmly to the soil; then raise the lower end of the board until it is level with the upper end. It is level when the bubble in the carpenter's level is between the two indicator lines.

To get the vertical distance, measure the distance from the lower end of the board (while held level) to the soil surface immediately below. Express this as percent slope by using the following formula:

$$\text{percent slope} = \text{vertical units divided by horizontal units} \times 100$$

Example: If the vertical distance is 20 centimeters and the board is 4 meters long:

$$20 \text{ centimeters} / 4 \text{ meters} = 20 \text{ centimeters} / 400 \text{ centimeters} = 5 / 100 \times 100 = 5\text{-percent slope}$$

Using a String Level

You can also teach farmers to measure slope with a string level (a mason or carpenter's string level). This is a small (about 10 centimeters long), inexpensive, simple device, which you should be able to find in your host country. It has a bubble in the middle, and a loop on each end through which to pass a string. It can be used two different ways:

Use this small level in the same way as the large carpenter's level above. Tie the string level to a board or rod, as above. (A board is more accurate than a string, especially during high winds.) It works well for marking the elevations when making bench terraces or digging drainage ditches with a specific grade or slope.

Alternatively, use it suspended from a string. Measuring this way may require two people.

Pass a 2- or 4-meter length of strong string through the two holes included for this purpose at the top of the instrument. Be sure the string is strong and exactly 2 or 4 meters long. Slide the level near the down-slope end of the string.

While you hold one end of the string on the ground, another person should take the other end around, stretch the string, and lay it on the ground so that it is pointing straight down the hill. Now raise the down-slope end of the string and stretch it very tight, while the other person holds the other end of the string snugly to the ground. When the small bubble in the instrument is exactly in the center, between the instrument indicator lines, the string is level.

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With the string held in that level position, measure with a ruler the vertical distance from the down-slope end of the string to the soil surface immediately below.

If the vertical distance is 6 centimeters and the horizontal distance is 2 meters (200 centimeters), percent slope = $6/200 \times 100 = 3$ percent.

Using a Calibrated A-Frame

Begin by studying and understanding in advance the entire section below, which deals with the A-frame level device—how to make it, how to calibrate it, and how to use it.

Go to a spot on a hillside that appears to have an average slope. Put one leg of the A-frame on the ground and point the other leg straight down the hill.

Keeping the first leg firmly on the ground and keeping the two legs lined up to point straight downhill, bring the lower leg to the elevation required to make the hanging string come to the level marker. Keeping the instrumental level position, measure the vertical distance from the bottom of the lower leg to the ground. Use a ruler to measure in millimeters. Repeat this five or six times at different locations. Compare it to other methods. To get more accuracy, make a special A-frame with 2 meters of space, instead of 1 meter, between the legs.

How to Make and Use an A-Frame

The A-frame, though crude and simple, is adequate for determining level contour lines (i.e., lines at 0-percent slope). Once farmers understand how this simple device works and its importance to them, they use it with pride. Most of the lines are surprisingly accurate. Its simplicity encourages a farmer to demonstrate it to a neighbor. The idea spreads quickly.

The farmer needs a sharp knife (machete, bob, cutlass), three poles, a piece of cord, string or wire, and a rock. The poles should be sturdy enough to stand upright without bending under a little stress.

1. Tie two of the poles together at the top, with the bottom of the poles spread out a bit. Tie the tops very securely, cross wrapping so they do not slip.
2. Tie the other pole as a horizontal brace across the other two poles (with their legs spread apart) to form the letter "A." The bottom of the A-frame should have the bottom of the legs exactly 1, 1.5, or 2 meters apart so distance can be measured with it. Tie both ends very securely. Be sure they cannot slide. Ideally, in addition to the string wrapping, all three joints should have a nail or wooden peg driven through them, in order to help keep the poles from slipping.

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3. Tie a free-hanging cord at the top point of the A-frame so it is centered, swings free, and hangs down below the crossbar.
4. Tie a rock to the bottom end of the cord so that it swings free below the crossbar. A plumb bob would be best, but a rock will work.
5. Now find the spot on the crossbar that can indicate when the legs are level on the ground. The cord-plus-rock in a state of rest will hang at a true vertical line with the earth. Therefore, the legs are level at the point indicated by the string when it has ceased swinging. To do this:
 - a. Stand the A-frame up, with the two legs standing on level ground. If the ground is not level, drive two strong stakes (pegs) vertically into the ground so they are exactly the same distance apart as the bottom legs of the A-frame (so the bottom of the A-frame legs can sit on top of the vertical pegs). The tops of the pegs should be as level as possible.
 - b. Place the A-frame legs on top of the pegs. Let the cord and rock come to a state of rest. Be sure the wind is not blowing the cord at an angle. Mark with a pencil on the crossbar the point at which the cord crosses it.
 - c. Now rotate the frame so the placement of the legs is reversed. The left leg will now be where the right leg was, and the right leg will be exactly where the left leg was.
 - d. When the cord comes to rest again, mark again on the crossbar the point at which the cord crosses the crossbar. There will be a space between the marks unless the pegs are level. If they happened to be level, the marks would be on top of each other.
 - e. Mark the point, which is halfway between the two marks on the crossbar. When using the A-frame in the field, you will know the two legs are level on the ground when the free-swinging rock-line comes to rest at the exact midpoint on the crossbar.
 - f. Make a notch on the crossbar at this point with a knife or a machete so you can see it easily and it cannot be erased.
 - g. The legs are level when the cord-and-rock hangs directly over the notch.
 - h. You are now ready to run the first contour line around the top of the hill.
6. Calibrate the A-frame from time to time. To do this, periodically repeat the same steps for finding the center point. Even though the A-frame is well made, its accuracy should be checked, i.e., calibrated.

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How to Find Contour Lines Using the A-Frame

1. Start near the top (highest point) of the field.
2. Cut a number of stakes to use for marking the level lines (contour lines).
3. Drive in the first stake near the top edge of the field. This will be the marker stake from which you will lay your contour lines.
4. Work in a level line (contour) around the hill. Position one leg of the A-frame so that it is slightly above and touching the first stake. Move the other leg of the A-frame so that the cord is in front of the notch on the crossbar—the notch that marks a level position point on the crossbar. Have the cord swinging free when the reading is made.
5. Keeping the cord carefully at the level point, sink another stake into the ground. This one should be slightly above and touching the second leg of the A-frame.
6. Move the A-frame, touching one leg of the A-frame to the last stake that you drove. (Alternate the leading leg of the A-frame, swiveling one leg and then the other leg into the lead position as you work around the hillside.)
7. Always adjust the leading leg of the A-frame, moving it until the cord is in line with the center notch, your level position marker. Drive the pegs alternately above and below the legs of the A-frame, barely touching.
8. Proceed around the field until you have completed the length of the row. You have now set forth the first contour row in the field. Marking the remainder of the lines will come much more quickly and easily.

How to Control Gullies

Prevention is the best gully control. Sometimes small gullies can be erased by using a contour diversion ditch above the area, plowing across the gullies on the contour, and planting the area with appropriate grasses and legumes. If larger gullies are present, use a contour diversion ditch and different types of check dams as shown below.

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Appendix A-1. Contour diversion ditch and check dams can effectively control gullies. Tree seedlings and grasses and/or legumes can also be planted below the ditch to control raindrop splash erosion over the area.



How to Enhance Fertility if Soil Testing Laboratories and Commercial Fertilizers are Unavailable

How to Test Soil Acidity with a Quick Test on the Farm

1. If a soil-testing laboratory is available and affordable, by all means have a fertilizer and pH test done at the laboratory and follow its recommendations where possible.
2. Where no soil laboratory is available, the agricultural worker can test for pH with a test that can be done on site. It will not be as accurate as a laboratory, but it will give a good indication.
3. Take a composite soil sample as if you were sending it to a soil-testing laboratory. (See Chapter 1 for directions.)
4. While you are testing the soil, you may wish to dig deeper and get separate samples from the soil to check its pH. You would make composite samples of the subsoil as you have done for the topsoil. You would, of course, test topsoil and subsoil separately.
5. Take one-half cup of soil from the well-mixed composite sample and place it in a clean plastic or glass bowl or jar. Add one cup of clean, untreated drinking water or, better yet, clean rainwater. Mix thoroughly and let the sample set for 5–10 minutes or longer.
6. Remove a small sub-sample from the top after the soil has settled.

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7. If you are testing with liquid tester, follow the directions accompanying liquid kits. They come in various forms.
8. If you are using strips or ribbons of testing paper, put several drops of the soil water on the bit of paper ribbon; or follow the manufacturer's directions. Read the pH from the color chart. You can order these as follows:
9. Check with your in-country Peace Corps office for other possible sources of testing liquid, ribbons, or paper.

How to Estimate Fertilizer Requirements Without a Soil Test Laboratory

1. List the crops the farmer grew last year. Estimate the crop yields.
2. Use Table 1-8 from Chapter 1 to reach a rough estimate of plant nutrients drawn from the soil last year, especially nitrogen, phosphorus, and potassium.
3. Try to replace these and add 30–50 percent more to the field. Do calculations in kilograms nutrient/hectare.
4. Compare this farmer's crop yields to crop yields of good soils in the area.
5. Watch for signs of nutrient deficiencies. Use Table A-3 below.

How to Supply Required Plant Nutrients from Soil Cover

Plan to fully use the farm's potentials for producing high quality organic fertilizer.

1. Begin by reviewing Table 1-9 from Chapter 1 for nutrient content from manure, compost, etc.
2. Analyze and plan what the farmer can produce.
3. Use the farm's crop production capabilities well.
4. Plan for, make, and use all the high-quality compost the family labor and farm can supply.
5. Grow as many green manure crops as possible (see Chapter 3.)
6. Use crop rotation, planting food grains alternately with other (especially legume) crops. Example: corn following beans.
7. Know and maximize the use of animals' manures, using the table below (A-2) for values.

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8. Apply organic fertilizers (manure, compost, green manure crop leaves) in narrow row strips and work it into the soil. Use the "V" ditch row as in conservative tillage, if possible.
9. Use some commercial fertilizer if possible.

Appendix A-2. Approximate Composition of Various New, Wet Manures

Fresh Manure with Bedding or Litter	Percent Moisture	Kg of Nutrients per 1000 kg of Manures		
		N	P20	K20
Chicken*	70 percent	11	11	5
Sheep and Goat	70 percent	10	7.5	10.5
Goat	86 percent	5.5	2	5
Horse	80 percent	6.5	2.5	6.5
Pig	87 percent	5.5	3	4.5
Rabbit	60 percent	15	10	10

**Chicken manure is usually higher than this.*

Gather, accumulate, and use all manure. Keep animals penned and cut and carry feed to them, thus collecting manure in one place. Keep manure stored in a shady, dry place. If the manure is exposed to hot sunshine or rainfall, the fertilizer value will be reduced by more than 50 percent in a short time. The fertilizer value of the manure will vary with the nutrient content of the foods the animals eat. For example, note the potassium value (K) of maize stover (stalks and leaves) as compared to that of sorghum (See Table 1-8). Where bedding from straw or stover is used for animals in stalls or in covered pens, the nutrient from urine and manure in the bedding makes a contribution. **Caution: Mix animal manure (especially chicken manure) well with soil when applying, to avoid burning the plants.**

How to Check Soil Fertility Status while Crops are Growing

Deficiencies in plant nutrients mean reduced yields at harvest time. Consider the nutrients needed to grow a healthy maize crop. In Table 1-7, you saw that maize requires heavy amounts of nitrogen (N) and potassium (K) to produce a crop. The demand increases greatly as yields increase. If these are deficient, the yield can only be significantly reduced.

Row Testing

1. When you are applying fertilizer to the field, use "test rows" to decide whether the crop needs more fertilizer.

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2. Make a map of the field with locations of different crops. Apply regular fertilizer amounts to the whole field.
3. Choose two separate locations in the field. In addition, mark off 25-meter lengths alongside each other in three adjacent rows. On one row, leave the regular field fertilizer treatment. On the 25-meter strip adjacent to it, add 50 percent more fertilizer. On the third adjacent 25-meter strip, add 100 percent more fertilizer. Record the location so that you can observe the harvest later.
4. Repeat this in the second location.
5. Observe the test plots throughout the growing season for rate of growth, color, and yield. Harvest separately when crops are mature. This should show some interesting results for comparison.

Read Hunger Signs of Plants

Symptoms of nutritional deficiencies or “hunger signs” can help the farmer determine what particular plant nutrients are needed; i.e., what hunger signs are specific to N, P, K, or other nutrients.

In the absence of a fertilizer test from a soils laboratory, the farmer must watch crops carefully and learn to identify specific crop hunger signs.

Certain crops are easy to read as indicators of a soil’s fertility status; i.e., their deficiency signs show up clearly. Maize plants are good indicators: they clearly show deficiencies from nitrogen, phosphorus, potassium, calcium, magnesium, and other nutrients.

Learn the signs of nutrition deficiency of maize and teach them to others. This will be a fair indicator of the soil deficiency for many other crops. This can help guide the farmer’s fertilizer program.

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Appendix A-3. Signs of nutrient Deficiencies in Plants

Plant	Growth	Leaf Color	Flowers & Fruit	Other Comments
Nitrogen Deficiencies				
Grass family (maize, rice, millet, wheat, sorghum, pasture grasses)	Slow growing, spindly stems	Pale green or yellow green. As plants grow older, lower leaves show yellowing of the tips, then yellowing moves up the leaves in a V-shaped pattern; often there is a yellowing of lower leaves or all leaves have a yellow-green appearance. Lower leaves may turn brown and die.	Caution: Drought can also cause browning of lower leaves.	
Legumes (field beans, soybeans, etc.)		The leaves are pale green with a slight amount of yellowish color. Look first at the lower leaves where it begins.		Legumes make their own nitrogen if the appropriate Rhizobia bacteria are present in the soil. For the Rhizobia to be healthy, the soil must not be too acidic and must have the needed soil nutrients for normal growth. When Rhizobia are performing abnormally, nitrogen deficiency signs appear on legume plant leaves.
Other crops	Retarded growth	Leaves are pale green or lack green color on leaves and stems.	Lower yields, smaller fruit	Signs are the same for many vegetables, as well as other crops.

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Plant	Growth	Leaf Color	Flowers & Fruit	Other Comments
Tomatoes	Slow growth, smaller leaves	Change in color, fading through various shades of green leaves to pale green and then yellow. Look also at top of plant where green becomes lighter.	Flower buds turn yellower and fall off; fruit is small	
Cucumber	Stunted	Few leaves, pale green	Pale green fruit	
Radish	Slow, stunted	Small yellow leaves		
Potato	Stunted	Yellow leaves	Smaller, fewer tubers	
Phosphorus Deficiencies				
Grass family	Retarded rate of growth; slow rate of maturity;	Purplish leaf coloring		Phosphorus is concentrated in the youngest growing tissues, the tips of roots, and shoots.
Maize	Spindly stalks	Purplish leaf coloring and small mature leaves	Fewer rows of grain on the cob	Maize that is developing kernels will transfer phosphorus from leaves to grain to meet phosphorus deficiency. Phosphorus deficiencies are not as easily noticed as in grasses.
Legumes	Slow growth; fewer side branches	Younger leaves become dark green but are smaller than normal.	Flowering and maturation retarded; fewer seeds	

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Plant	Growth	Leaf Color	Flowers & Fruit	Other Comments
Other crops (vegetables)	Slow, delayed maturity; hunger signs appear early on young plants and continue to harvest	Underside of leaves of tomatoes may show purplish color. Turnips and other cabbage family plant leaves tend to turn purple (cabbage, brussels sprouts, broccoli, etc.).		Crop yields are reduced.
Potassium Deficiency				
Grass family	Signs appear later when plant is several weeks old	Margins or edges of the lower leaves turn yellow, beginning at the tip, then brown, and die. Leaves may appear too long and thin for the plant height.	Stalk has relatively short internodes	Potassium starvation produces a very weak plant with badly damaged leaves.
Legumes		Look around edges of leaves for irregular yellow mottling.		
Cabbage Cucumber		Many vegetables show discoloration along the leaf edges. Cabbage leaves show bronze color along edges, which spreads inward as leaves grow older, later showing brown spots. Leaves show firing—brown then yellow on leaf edges.		

A Summary

- Phosphorus deficiency signs appear early on young plants.
- Potassium deficiencies appear late. Plant stalks will be weak.
- With nitrogen deficiency, the yellowing and the brownish color goes up the middle of a maize leaf, beginning at the leaf tip.
- With potassium deficiency, the yellow or brown coloring stays on the outside edge of the leaves, beginning also at the tip.

When you see signs of nutrient deficiency, there is little you can do to help the current crop unless you have some commercial fertilizer or manure available that you can immediately apply. The main benefit of these signs is to help you plan the plant nutrient needs for next year's crop.

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For example, if nitrogen deficiency is noticeable across the field, by all means persuade the farmer to use crop rotation and plant demonstration plots of several green manure crops. These crops will also help with phosphorus and potassium deficiency.

If phosphorus and/or potassium deficiency signs are showing, encourage the use of some commercial fertilizer high in P and K as a side dressing to the row, or in the bottom of the seedbed at planting time. Also encourage the use of more manure and compost in the row under the seed at planting time.

How to Inoculate Legume Seeds with Rhizobium Bacteria Before Planting

All legume seeds, both field crops and trees, need to be treated with the special bacteria Rhizobium unless the same legume plant has already been grown in the soil where the seeds are to be planted. Legume roots house the Rhizobium bacteria that manufacture nitrogen fertilizer. The bacteria take elemental nitrogen from the air and convert it into nitrogen fertilizer. They will produce enough nitrogen fertilizer for the plant to use and have extra left over for other nearby plants.

Seed treatment is done by taking topsoil from around growing legume roots and rubbing it on the new seed. Each legume species requires a specific strain of Rhizobium. If you cannot find soil containing the needed Rhizobium, you can order pure Rhizobium from a number of places.

How to Treat Tree Seed Before Planting

Some tree seeds have a tough water resistant coating. The seed skin is tough. The following treatments are recommended for treating the seeds prior to planting. Most tree seeds will germinate if soaked in water all night before planting the next morning. Other tree seeds are particularly tough. The seed of the legume tree *Leucaena*, for example, needs extra help. You can use any of the following methods of scarification.

- Take a knife blade or sandpaper and nick or scratch the backside of the seed. This breaks the tough skin so water can penetrate and usually produces nearly 100 percent germination.
- When dealing with large volumes of *Leucaena* seed, you may wish to use hot water treatment. Take 1 pound of seed in a small bucket. Heat water in metal bucket or pot until it boils. Pour exactly 1 gallon of boiling water over the seed and leave it alone for 4 minutes. Then quickly pour off the hot water and put the seed on a flat surface to drain dry. This weakens the seed coating so water will enter.
- Treat legume seeds with the appropriate strain of Rhizobium before planting.

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How to Determine the Rainfall Infiltration Rates of Soils

Appendix A-4. Classification of infiltration Rate

Rate	Description
Excellent	All rainfall water enters the soil during heavy rainstorms. You will usually find this kind of water disappearing act if you pour a bucket of water on dry beach sand. No runoff results.
Good	This nearly falls in the “Excellent” category. There is some runoff during heavy rainstorms, but less than 10 percent of the total rainfall.
Moderate	Some runoff can be noticed during storms of medium intensity, and much runoff during major, highly intensive storms.
Poor	Most of the water runs off during moderate rainstorms and all of the water runs off (except a small fraction) during an intensive storm.

Note: remember, you will always have runoff if the soil is not deep enough to hold the volume of water from a rainstorm. In addition, if one rainstorm follows another after a few hours, the soil volume may be full of water already. Much runoff will then occur since the soil storage is already full.

For this reason, in tropical conditions you should always install contour drainage ditches and exit control drainage ditches and exit control. They will be needed.

How to Distinguish Usable Soil Depth

1. Dig several holes in the field through the subsoil down to the parent material. If this is done toward the end of the rainy season, you can determine how deep different crops go into the subsoil.
2. The vertical distance from the top of the soil surface to the bottom of the subsoil can usually be considered the usable soil depth. However, be sure that plant roots are growing well into the subsoil.
3. As a rough method for discussion, the soil is divided into four classifications of depth. Remember that plant roots must be able to penetrate the subsoil and grow there. Be sure there are no restrictions in the subsoil (hard compacted layers, poor drainage, rock layers, or strongly acid subsoil). If there are such restrictions, this part of the subsoil cannot be considered in determining the usable soil depth. Plant roots must actually use the soil. (Example: The maize plant roots will penetrate up to 90 centimeters if the subsoil is relatively fertile. This could be your best test plant.)

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Appendix A-5. Depths of Types of Soils

Name	Depth of Usable Soil
Deep soils	90 centimeters or more
Moderately deep	50 to 90 centimeters
Shallow	25 to 50 centimeters
Very shallow	Less than 25 centimeters

How to Choose the Appropriate Methods of Soil and Water Conservation for a Given Situation

The table below lists 10 soil and water conservation technologies. It compares their effectiveness and appropriate use considering different slopes, soil depths, infiltration rates, drainage needs, construction costs, complexity, tools required, etc. It compares their contributions to soil fertility, usable byproducts, ease of fieldwork and maintenance, and limiting factors. You will also find recommendations for each one.

Appendix A-6. Guide to Choosing the Appropriate Technologies

Factors	Contour Ditches to Catch and Store	Contour Ditches Offer Slow Drainage	Loose Rock Barriers	Earth Barriers (covered with grass)	Grass Barriers (with ditches)
Construction Costs (Money & Labor)	Moderate labor	Moderate labor	Very moderate labor	Much labor if mainly done with hand tools	Moderate labor
Tools Required	Hand tool: A-frame	Hand tool: A-frame	Hand tool: A-frame	Hand tool: A-frame	Hand tool: A-frame
Complexity of Construction	Very simple	Very simple	Very simple	Simple	Simple
Maintenance Tasks	Minimal. Keep ditches clean	Minimal. Keep ditches clean	Minimal. Keep rocks in place	Keep earth mound intact with grass cover	Keep grass stands solid and ditches clean
Contribution to Soil Fertility	None	None	None	None	None
Bonus Byproducts (human food, animal feed, firewood, nitrogen fertilizer)	None	None	None	None	Cut and carry livestock feed

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Efficiency of Erosion Control (raindrop splash erosion)	Does not stop splash, but holds soil in ditch	Does not stop splash, but slows water runoff	Does not stop splash, but slows water flow	Does not stop splash, but slows water flow	Does not stop splash, but slows water flow
Rainfall Expected	Very heavy	Very heavy	Very heavy	Very heavy	Very heavy
Relative	Moderate to	Poor to	Poor to moderate	Poor to excellent	
Infiltration Rate Needed	good	moderate			
Soil Depth Needed	Moderate to deep	Various depths	Various depths Various depths	Various depths	
Percent Slope of Field	5 percent to 50 percent	5 percent to 50 percent	5 percent to 30 percent	5 percent to 20 percent	5 percent to 25 percent
Most Rain Captured and Stored?	Yes, if soil depth/ infiltration rate allows	Partially	Flow slowed	Yes, if soil depth/ infiltration rate allows	Yes, if soil depth/ infiltration rate allows
Factors	Legume Tree Barrier (with ditches)	Continuous Bench Terraces	Discontinuous Use Bench Terraces	Conservation Tillage (in row tillage) with Contour Drainage Ditches	Contour Drain Ditches with Green Manure Crop Leaving Mulch on Field
Construction Costs	Moderate labor and seed cost	Very expensive, one man/ year labor to construct one hectare Less expensive, one-half labor cost of continuous terrace	Less expensive than discontinuous terrace	Labor moderate plus cost of seed first year	
Tools Required	Hand tool: A-frame	Hand tool: A-frame cord level	Hand tool: A-frame cord level	Hand tool: A-frame	Hand tool: A-frame

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Complexity of Construction	Not simple; must have very close growing trees	Very complex for a good job	Complex for a good job	Follow very simple instructions; management needed	Very simple
Maintenance Tasks	Trim trees; keep grass stand under trees	Good management; moderate labor	Good management; moderate labor	Trim excess grass with knife; minimal	Keep ditches clean, mulch on surface
Contribution to Soil Fertility	Nitrogen fertilizer, mulch, organic matter	None	None	None	Nitrogen fertilizer, mulch, organic matter
Bonus Byproducts: (human food, animal feed, firewood, nitrogen fertilizer)	Nitrogen fertilizer, mulch, organic matter	None	None	Mulch	Beans for food or sale; feed for animals
Efficiency of Erosion Control (raindrop splash erosion)	Leaf mulch greatly reduces splash, slows flow; very heavy	Holds soil in place only	Holds soil in place only	Excellent	Very good
Rainfall Expected	Very heavy	Very heavy	Very heavy	Very heavy	
Relative Infiltration Rate Needed	Moderate	Good except for paddy	Moderate	Moderate	Moderate
Soil Depth Needed	Variable depths	Relative deep soils	Moderately deep	Variable depths	Variable depths
Percent Slope of Field	5 to 50 percent	Any slope (15 to 50 percent suggested)	Any slope (15 to 60 percent suggested)	5 to 50 percent	5 to 30 percent
Most Rainfall Captured and Stored	Yes, if soil depth/ infiltration rate allows	Yes, if soil deep enough	Much	Mulch cover stores water if soil is deep	Much if infiltration/ soil depth allows
Factors	Contour Ditches to Catch & Store	Contour Ditches Offer Slow Drainage	Loose Rock Barriers	Earth Barriers Covered with Grass	Grass Barriers (with ditches)

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Contour Diversion Drainage Ditch Needed at Top of Field?	Yes	Yes	Yes	Yes	Yes
Exit Control Drainage Ditch Needed?	Yes	Yes	Yes	Yes	Yes
Other Drainage Needs	None	None	Contour drainage ditches as needed	Empty into exit drainage ditch	None
Comments	If ditches spill over, space closer and dig them deeper. Empty into exit drainage ditch	Be sure all ditches have 1 percent fall toward exit ditch	Can plant vegetables against the upper side of barrier	Used to hold rainfall, guide runoff water slowly to exit drainage ditch	Grass hedges do not hold well at slopes above 25 percent; use trees instead
Limiting Factors	Do not use in shallow soils with poor infiltration	Use on shallow soil or very slow infiltration	Keep livestock from destroying	Effective on steep slopes when used with adequate ditches	Keep grass and solid ditches clean
Recommendations	All three of these are simple and effective technologies. A good way for beginners to start. Encourage the farmers to also use green manure cover crops		Earth barriers are often used to slow runoff outlet	Do not use grass barriers on steep slopes; instead use nitrogen-fixing trees	

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Factors	Legume Tree Barrier (with ditches)	Continuous Bench Terraces	Discontinuous Bench Terraces	Minimum Tillage (in row tillage) with Contour Drainage Ditches	Contour Drain Ditch with Green Manure Crop Leaving Mulch on Field
Contour Diversion Drainage Ditch Needed at Top of Field?	Yes	Yes	Yes	Yes	Yes
Exit Control Drainage Ditch Needed?	Yes	Yes	Yes	Yes	Yes
Other Drainage Needs	None	Appropriate contour drainage ditches as needed	None	None	None
Comments	Closely deep-rooted N-fixing trees do OK. Up to 50 percent slope if supported by adequate contour drainage ditches	Excellent for high cash value crops with good fertilizer programs	Excellent for steep slopes, perennial crops, orchards, tea, and coffee	(Contour drainage ditches about 20 meters apart or closer if needed). An Excellent system!	Keep mulch on surface and ditches clean
Limiting Factors	Finding the right tree. Needs some management	Need good management for operation and maintenance. Keep livestock out	Need good management for operation and maintenance. Keep livestock out	Needs good cover of native grass to begin with, or seeded	Finding appropriate legume seeds. Keep ditches clean

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Recommendations	Search diligently for excellent tree legume seeds to produce 200 Kg/N/H	Where labor is plentiful and soil is deep; where some row crops are to be grown for market, use this type of terrace on moderate to steep slopes	Orchard terraces, individual tree, basic terraces all up to 60 degrees. For upland cultivated crops, only use on 15 to 50 percent slope	Farmers should begin with a small plot. They will want to increase it later	An excellent, quick, inexpensive way to control erosion and runoff. Expect two to three times increase in yields if using right legume seed
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Appendix 2: Resources on Soil and Water Conservation

Climate Smart Agriculture (<http://www.climatesmartagriculture.org/en/>). The website of the climate-smart agriculture approach is an entry point for essential information on how to make agriculture, forestry, and fisheries part of the solution to the negative impacts of climate change. It also offers a space for those who work on climate-smart practices to share documents and exchange information and views on what works and what doesn't when adapting to climate change and mitigating greenhouse gases in agriculture.

The International Fund for Agricultural Development (IFAD) (<http://www.ifad.org/>). A specialized agency of the United Nations, IFAD enables poor rural people to improve their food security and nutrition, raise their incomes, and strengthen their resilience.

Modernizing Extension and Advisory Services (MEAS) (<http://www.meas-extension.org/>). The objective for MEAS is to define and disseminate good practice strategies and approaches to establish efficient, effective, and financially sustainable rural extension and advisory service systems in selected countries. Its goal is to help transform and modernize these extension systems so they can play a key role in both increasing farm incomes and enhancing the livelihoods of the rural poor, especially farm women.

International Center for Tropical Agriculture (CIAT) (<http://ciat.cgiar.org/soil>). Its crosscutting research links CIAT's research in crop improvement and policy analysis to vital work on agricultural production systems across landscapes.

Global Soil Map (<http://www.globalsoilmap.net/>). This global consortium aims to make a new digital soil map of the world using state-of-the-art and emerging technologies for soil mapping and predicting soil properties at fine resolution. This is intended to assist better decisions concerning global issues such as food production and hunger eradication, climate change, and environmental degradation.

Global Soil Forum (<http://www.iass-potsdam.de/research-clusters/global-contract-sustainability/sustainability-governance/global-soil-forum>). This forum provides a multi-stakeholder platform that promotes knowledge exchange, research, and policy action on sustainable soil management. In cooperation with leading actors in the field, the Global Soil Forum initiates processes that foster the translation of soil knowledge into action. Furthermore, it acts as a voice in policy discussions advocating for soil management that contributes to sustainable development and an equitable access to this finite resource.

International Biochar Initiative (IBI) (<http://www.biochar-international.org/biochar/soils>). IBI has guidelines regarding biochar and soils, and a number of publications on biochar and its effect on specific soil types in specific conditions.

The Rural Poverty Portal (<http://www.ruralpovertyportal.org/home>). The Rural Poverty Portal is a website where rural poor people, policymakers, donors, research institutes,

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nongovernmental organizations, and other development partners can share information about eradicating rural poverty.

Optimizing Soil Moisture for Plant Production (<http://www.fao.org/docrep/006/y4690e/y4690e00.htm> - Contents Optimizing Soil Moisture for Plant Production). This book, intended for extension staff and other technicians, as well as farmer leaders, aims to provide a solid basis for sound, sustainable soil moisture management.

Food and Agriculture Organization (FAO) Forestry (<http://www.fao.org/forestry/en/>). FAO Forestry provides resources on forestry in developing countries.

Forage Tree Legumes in Tropical Agriculture (<http://www.fao.org/ag/AGP/AGPC/doc/publicat/gutt-shel/x5556e00.htm#Contents>). This book provides a comprehensive coverage of the latest information on the major tropical forage tree legume species and their evaluation and utilization in sustainable agricultural production systems.

Forage Tree Legumes in Alley Cropping Systems (<http://www.fao.org/ag/AGP/AGPC/doc/publicat/gutt-shel/x5556e0q.htm> - 5.2 forage tree legumes in alley cropping systems). This book provides a comprehensive coverage of the latest information on forage tree legumes in alley cropping systems.

On-Farm Composting Methods. (<http://www.fao.org/docrep/007/y5104e/y5104e00.HTM>). This book from FAO provides up-to-date information on compost production methodologies to the scientific community, extension workers, NGOs, farming communities, and other stakeholders concerned with agricultural development. Furthermore, it is intended as an instrument for promoting the wide-scale adoption of efficient, rapid composting technologies, with the ultimate objectives of improving soil productivity in developing countries and protecting the environment from degradation.

Managing Cover Crops Profitably (<http://www.sare.org/Learning-Center/Books/Managing-Cover-Crops-Profitably-3rd-Edition/Text-Version>). There is a cover crop to fit just about every farming situation. The purpose of this book is to help you find which ones are right for you.

Vetiver Grass: A Thin Green Line Against Erosion (http://www.nap.edu/catalog.php?record_id=2077). This book assesses vetiver's promise and limitations, and identifies places where this grass can be deployed without undue environmental risk.

Impact of Contour Hedgerows: A Case Study (<http://lib.icimod.org/record/21370>). This book describes the results of two experiments to investigate different aspects of SALT, including soil erosion, soil fertility, and hedgerow/crop competition for moisture and nutrients. SALT can be effective in subtropical and temperate regions, and can reduce soil erosion to a very low level and increase productivity. Some of the different factors affecting its success are discussed.

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More People, More Trees! (<http://www.iied.org/more-people-more-trees-0>). This online video shows two decades of progress in addressing soil erosion in Burkina Faso and Kenya, with significantly improved rural livelihoods and farm productivity.

Soil Conservation Techniques for Hillside Farms [R0062] (<http://collection.peacecorps.gov/cdm/ref/collection/p15105coll3/id/82>). This Peace Corps publication provides basic information to help design plans for the conservation of soils and the management of water runoff in small hillside plots. It is based on experiences with small hillside farms in Honduras, but can be used by Volunteers worldwide working in the same program area. It takes into account a lack of resources, as well as commonly encountered constraints. It suggests various crops and types of compost piles to use.

Appendix 3: Weight and Measurement Equivalents or Conversions

Distance		
1 inch	= 2.54 centimeters	= 25.4 millimeters
1 foot	= 0.305 meter	= 30.48 centimeters
1 yard	= 0.9144 meter	
1 mile	= 1.61 kilometers	= 5,280 feet
1 kilometer	= 1,000 meters	= 0.6214 mile
1 meter	= 100 centimeters	= 1,000 millimeters
1 meter	= 3.28 feet	
1 centimeter	= 0.3937 inch	= 10 millimeters
1 millimeter	= 0.039 inch	= 0.1 centimeter
1 micron	= 10^{-4} centimeter	= 10^{-6} meter
10^{-6} meter	= 1 micrometer	
Volume		
1 kiloliter	= 1,000 liters	= 1 cubic meter
1 liter	= 1,000 milliliters	= 1,000 cc
1 milliliter	= 1 cc (exactly 1.000027 cc)	
1 fluid ounce	= 29.57 milliliters	
1 US gallon	= 3.785 liters	
1 Imperial gallon	= 4.546 liters	
Weight		
1 kilogram	= 1,000 grams	= 2.2 pounds
1 gram	= 1,000 milligrams	= 0.035 ounce
1 milligram	= 1,000 micrograms	= 1/1,000 gram
1 microgram	= 10^{-6} grams	= 1/1,000 milligram
1 nanogram	= 10^{-9} grams	= 1/1,000 microgram
1 pound	= 0.45 kilogram	= 16 ounces
1 ounce	= 28.35 grams	