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# INTENSIVE VEGETABLE GARDENING FOR PROFIT AND SELF-SUFFICIENCY

PEACE CORPS PUBLICATION NO. R0025

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1111 20th Street
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Abridged Dewey Decimal Classification (DDC) Number: 635

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# Intensive Vegetable Gardening for Profit and Self-Sufficiency

Peace Corps Publication R0025

# Preface

*Intensive Vegetable Gardening* replaces an earlier publication of the same name that was produced by the Peace Corps in 1980. This revision was completed in 2014 under contract with EnCompass LLC, through Feed the Future funding from the United States Agency for International Development (USAID). The Peace Corps review team included Specialist Greig Yeitch and Expert Consultant Lee Lacy. The original manual was developed from material produced by Volunteers and staff members in Washington, D.C., and at Peace Corps posts throughout the world.

As part of the United States' "whole of government" effort to address food security in the developing world, the Peace Corps has edited and revised several existing technical manuals designed for use by Volunteers. Most of these materials were created in the late 1970s and early 1980s and were written by different subject-matter experts employed or contracted by the Peace Corps. They have been revised with funding provided to the Peace Corps by USAID's Bureau of Food Security.

Given Volunteer and staff needs to access information on a wide range of topics related to food security, these manuals and their accompanying references were selected, reviewed, and updated by subject-matter experts. Although a few years have passed since first written, the content covered in these manuals, particularly the basic concepts, has changed very little, if at all. Importantly, references in each of the manuals have been reviewed and updated, where necessary, and websites have been added to allow the reader to locate additional and more recent supporting content.

The purpose of this manual is to demonstrate how smallholder farmers and garden producers in tropical or semi-tropical climates can increase their production. This will increase their income and will contribute to more environmentally resilient food systems. The methods introduced in this manual will help Volunteers working with smallholder farmers to improve gardening practices.

A considerable amount of information regarding the importance of soil preparation and maintenance is included in this manual, but additional information is available in the following manuals:

*Soil Conservation Technique for Hillside Farms* (R0062)

*Soil and Water Conservation for Small Farms in the Tropics* (R0084)

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# Overview

Intensive vegetable gardening means that the farmer's labor, land, and resources are used to achieve maximum yields in the smallest possible area.

The advantages of intensive vegetable gardening are as follows:

- Four times as much produce can be grown per acre of land planted
- Half as much water is required per pound of produce.
- Soil fertility is maintained and improved to increase future yields.
- The methods are land intensive and labor intensive so that the best use is made of a land's resources.

These characteristics of intensive vegetable gardening have always been relevant and important to people who have difficulty accessing productive inputs, but they take on a special relevance in relation to climate change, which increases the possibility of social, economic, and ecological uncertainty. Intensive vegetable gardening, because it employs "no regrets" techniques (such as sourcing productive inputs locally, building soil fertility, and efficiently using space) is considered to be a method of building resilience in the food-provisioning system.

**Box 1-1: Resilience, Adaptive Capacity, and Vulnerability**

Adaptive capacity refers to the ability of people to effectively confront and have an impact on the factors that affect their own well-being. In the case of intensive vegetable gardening, sourcing productive inputs locally, for example, enables more control over productive output than in a system where inputs must be imported. "Resilience" refers to the ability of a system to cope with uncertainty and change, and still function productively. A system that can deal with more "shocks" and still function is considered more resilient than a system that is unable to handle perturbation. The concept of vulnerability draws attention to the many different ways that people are negatively affected by social and environmental factors. Poverty is one way that people can be vulnerable, but there are many others, such as gender, ethnicity, or geographic location.

The increased production of four times' normal amounts may not be achieved during the first or second season, but significant increases will definitely be achieved with the very first crops. The speed with which increased production is achieved depends solely upon the farmer's ability to improve and maintain the fertility, texture, and structure of the soil within the natural limits of soil and environmental conditions of the land. To accomplish this, the farmer must apply organic manures, compost, soil amendments, and inorganic fertilizers in a manner that will provide balanced nutrition for productive, healthy plant growth.

# Overview

This manual will help the intensive gardener develop a practical knowledge of soil fertility. Through intensive vegetable gardening, increased production on limited lands is achieved, thus increasing the profits and incomes of the smallholder farmer.

There are critical food shortages throughout the world and countries are engaged in self-reliance programs to become more self-sufficient in food production. Many small plots of land can be put to more productive use through the methods introduced in this manual.

In short, this manual provides the knowledge to help grow more food on less land. Doing so will increase incomes and provide for a better supply of food for the family, the nation, and the world.

The plant is the basic unit of agriculture. No form of life can live on earth without the green plant and its ability to convert sunlight and raw materials into food for man and animals.

The farmer must have a basic working knowledge of plant structures and their functions. This knowledge gives the farmer a better understanding of plant processes of crop plants. It helps the farmer understand the problems and needs of crops so that he or she can improve crop productivity.

## Plant Structure

Plants have two important parts: the root system below ground, and the shoot system, which is above ground. The root system absorbs water with nutrients from the soil and serves to anchor the plant. The shoot system is made up of the stem, bearing leaves, branches, flowers, and fruits.

### Roots

**Figure 1-1: Roots**

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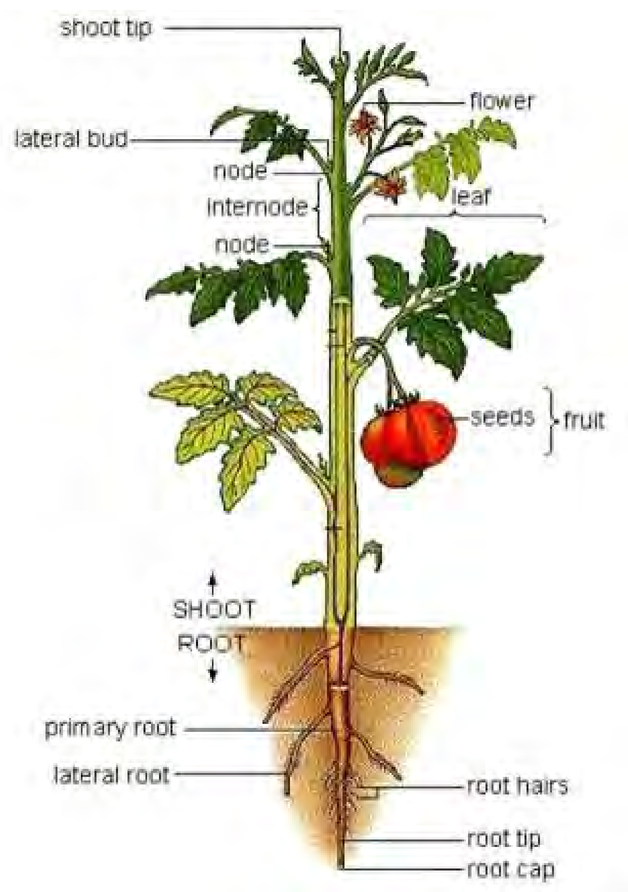


Roots have two main functions: to gather and absorb food and moisture from soil, and to store and transport these nutriments to the above-ground parts of the plant (the shoot systems). The process of absorption is performed by the tiny root hairs. Root hairs are very small roots, finer than human hair, which absorb nutrients from their close contact with soil particles. The transport and storage of nutrients and water takes place in the larger roots.

Roots are an important part of the plant, especially to the smallholder farmer, because their growth and properties can be greatly influenced by human treatment of the soil. For the root and root hairs to live in the soil, there must be air. The roots must have oxygen to breathe and grow.

Roots take in nutrients for growth through root hairs. The more root hairs a plant has, the more nutrients it can take in. Many root hairs are lost when roots try to push through hard and tight soil. The basic principle of intensive vegetable gardening is to properly prepare the soil to allow for proper root growth.

Because roots are hidden in the soil, they are often neglected. The successful smallholder farmer must constantly strive for strong, healthy, and plentiful root growth, to produce stronger, healthier, and more plentiful crops.

**Figure 1-2: Photosynthesis**

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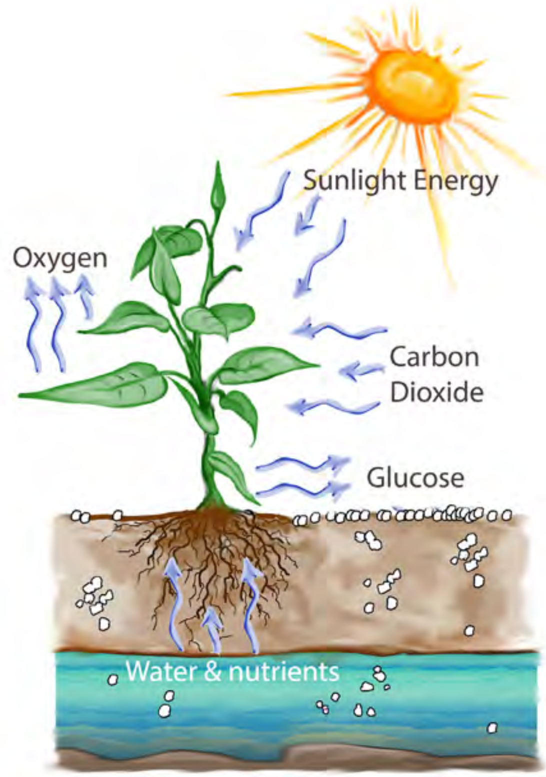



## Shoot System

The shoot system above ground is the most obvious part of the plant. It consists of the leaves, stems, flowers, and fruits. The leaves and stems are the most common parts of the plant, as they make up almost the entire exposed portion of the plant.

## Leaves

The importance of green leaves is easily overlooked. Besides telling us about the health and nourishment of our crop, green leaves are actually the food factory for the plant. In the green leaf, sugars and starches are produced by a process called photosynthesis.

Simply speaking, to make starches and sugars, the leaves take in carbon dioxide from the air and combine them with water and nutrients brought up by the roots from the soil. Sunlight is the energy used to perform the task. This process can only take place in the green parts of the plant.

## Stem

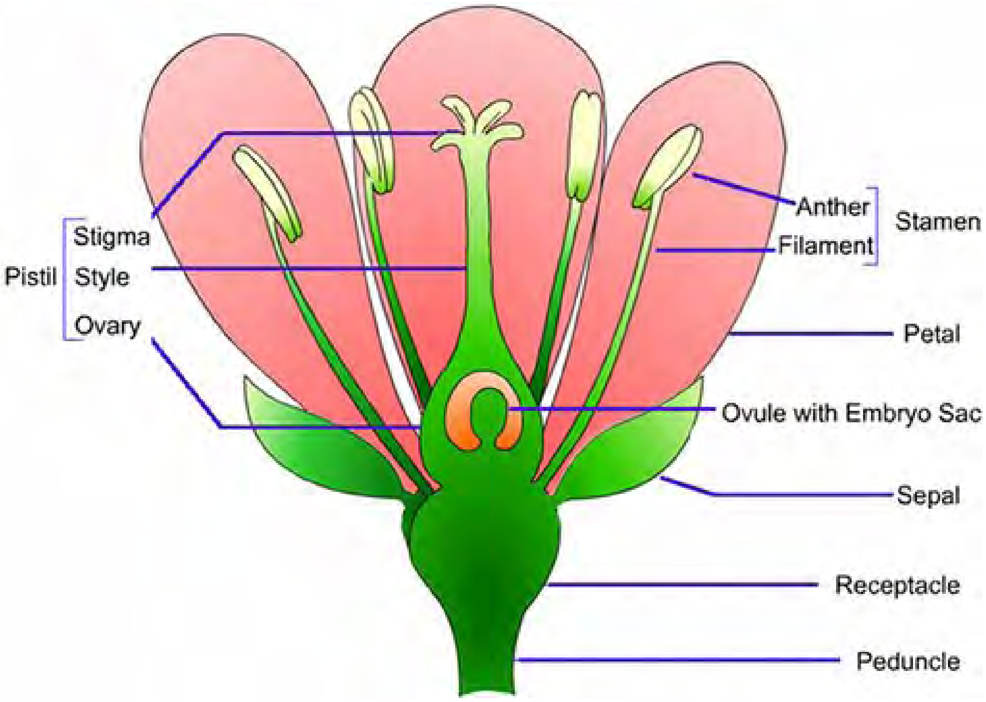
The stem's main purpose is transportation. Stems transport nutrients and water from the roots to the leaves, and transport sugar and starches from the leaves to the fruits and roots. The farmer must handle and cultivate plants very carefully so plant stems are not injured. They should receive the same care we give our own veins. That is, life flows through them!

## Flower

The flower is usually the most appreciated part of the plant, mainly because of its beauty and the tasty fruits that often follow. The flower is very important to the plant. It produces the seed for future generations. A complete flower contains the male and female parts. The male flower part produces a yellow powder called pollen. The pollen is carried to the female part by wind or, more often, by water, insects, or animals. In order to attract pollinators to carry pollen, many flowers have bright colors and sweet smells.

**Figure 1-3: Parts of the Flower**

Photo c/o creativecommons.org




* This flower contains both male and female parts (a complete flower). Some flowers may be of one sex, either male or female (incomplete flower).

## Seed

As every farmer well knows, the seed is another important part of agriculture. The seed consists of an embryonic plant inside and a supply of food. The stored food actually makes up most of the seed. Seeds are usually encased in a pod, as in peas, or in the fruit, like tomatoes.

The seed allows the farmer to plant new crops each season. Properly dried and stored, seeds can be kept for years and still produce a crop when planted. Seeds from healthy, properly cared-for plants produce stronger plants and healthier, larger crops. Proper storage can affect crop growth and yields. It is to the farmer's advantage to strive for good seed production and proper drying and storage.

By understanding and observing plant growth, the smallholder farmer is able to provide for the crops' needs. The serious farmer will become a keen observer of all aspects of nature that affect the farm. From observing and experiencing, he or she will learn and put to use the laws of nature to produce a more fruitful land.

**Figure 1-4: Seed Sprouting**

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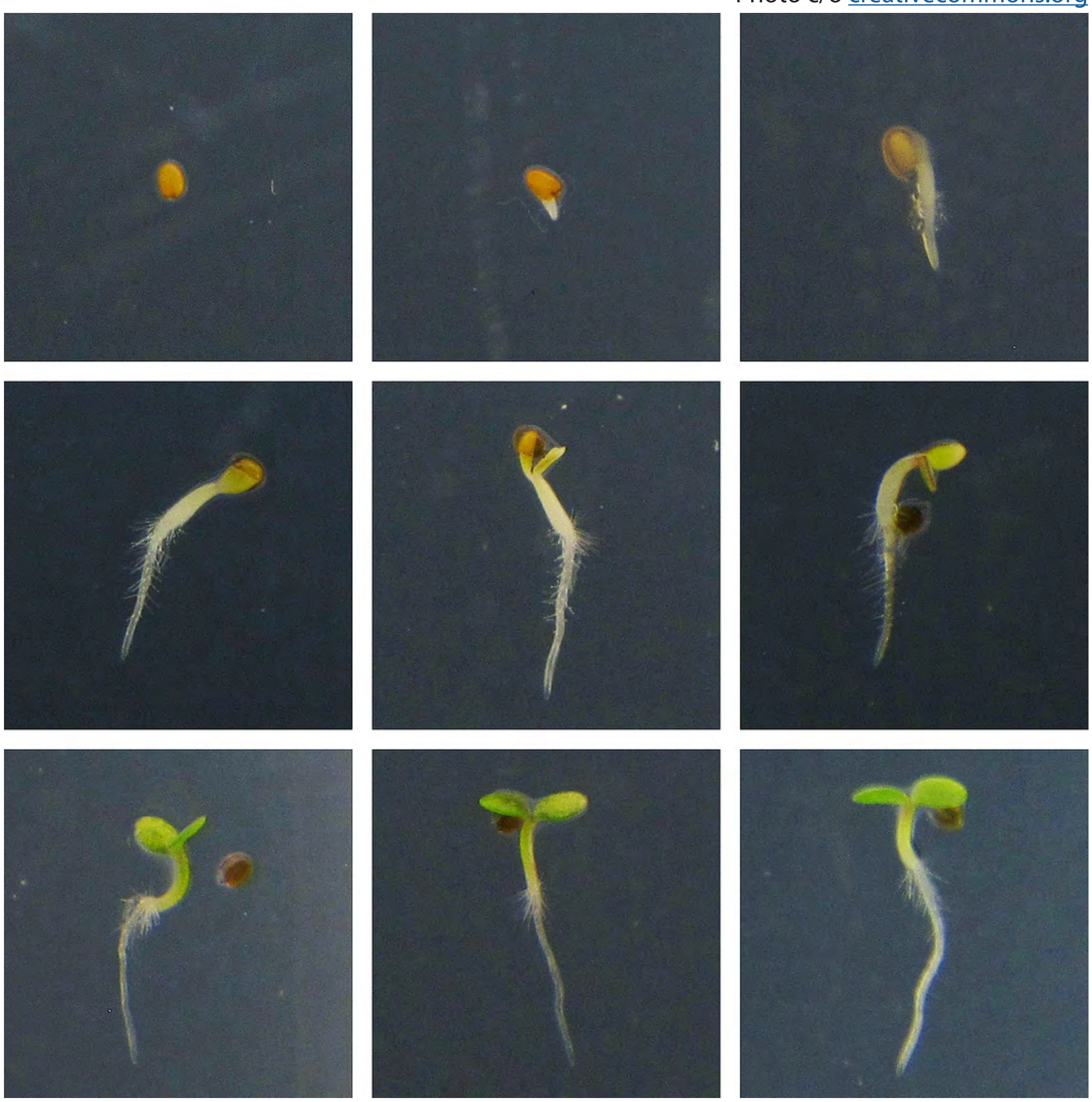
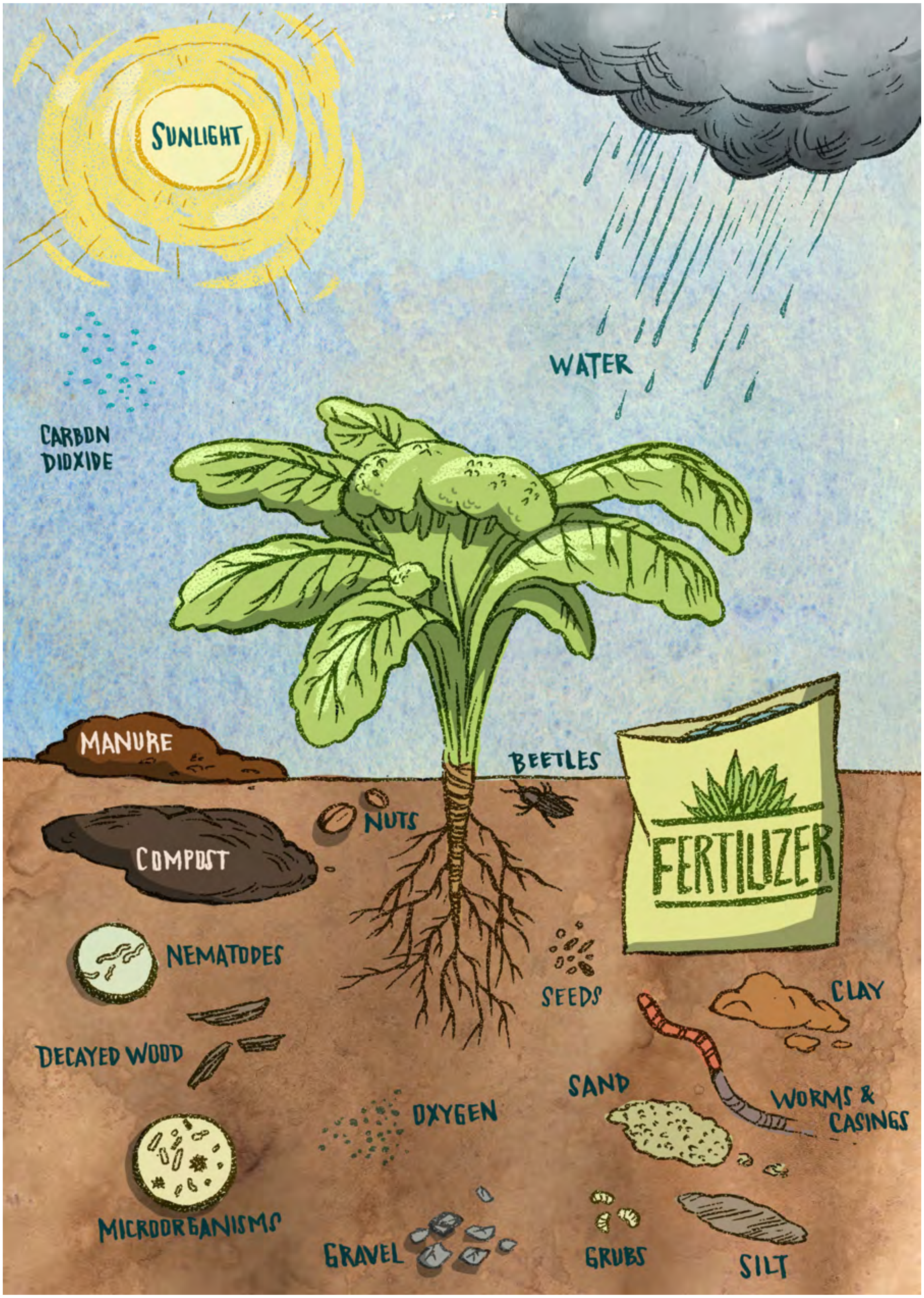


**Figure 1-5: Nature of Agriculture**



This section of the manual presents information needed to build and maintain soil fertility. The professional market gardener or farmer needs to understand the soil, and be able to properly access or estimate the physical and chemical properties of the soil. Good soil fertility is the foundation for producing increased yields through intensive market gardening.

To learn how to manage the soil's fertility, the farmer must first understand how nature has produced and maintained the soil's fertility for hundreds of years.

## Fertility Cycle of Soil

Understanding comes through observation. Nature's fertility cycle can best be observed in the deep forest, where the earth is covered with thick layers of dead and decaying leaves, plants, bark, insects, and molds. Leaves, branches, animals, insects, and soil microbes are constantly growing, dying, and collecting on the floor of the forest. This mulch of leaves, stems, and debris is put down layer upon layer as the seasons pass, becoming very thick in some places. As moisture collects in this mulch, conditions become right for soil microbes, and mold grows, causing the mulch to rot and decay. Slowly, coarse leaves and stems are changed into chemical nutrients by the rotting and decaying action of the soil microbes. In this way, the forest naturally produces its own fertility and continually replenishes it.

The lesson to the smallholder farmer is nature's law of return to the fertility cycle of the soil. To build and maintain soil fertility, the farmer must return decayed organic matter to the soil.

The soil's fertility can be thought of as a bank. If the farmer keeps drawing crops from the bank without returns, both the farmer and the bank will soon go broke. However, if the farmer is always returning and building a savings of fertility, he or she will reap bountiful crops, with "interest," for years to come.

## Glossary for Soil Study

The following list of terms and their meanings should be thoroughly understood by the professional market gardener. These terms will help the smallholder farmer to better understand and estimate the fertility and state of the soil.

### *Soil*

Soil is the loose top layer of the earth's surface that supports the growth of plants. Soil consists of minerals, organic matter, microorganisms, gases, and liquids.

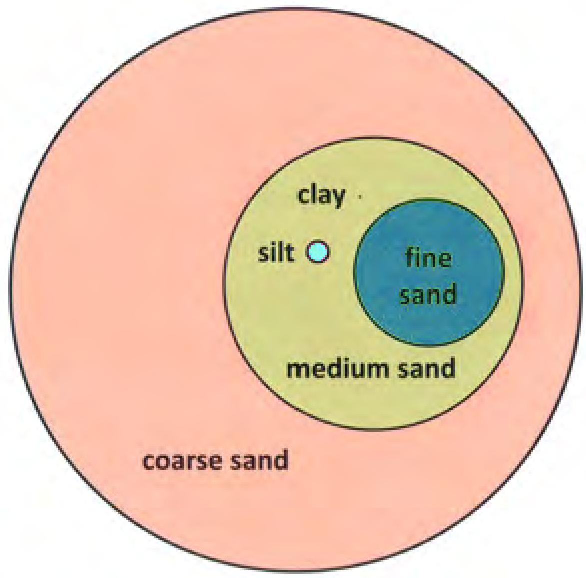
### *Texture*

Soil texture refers to the portions of differently sized particles that comprise soil. These particles vary greatly in size. There are stones, gravel, sand, silt, and clay particles. Many particles are too small to be seen without the use of a microscope.

### *Structure*

Soil structure is the arrangement, clumping, binding, or aggregating of soil particles, which forms a matrix of pores in the soil. The quantity, arrangement, and size of the pores determine the water-holding capacity, infiltration rate, permeability, and root penetration ability of a soil.

**Figure 2-1: Soil Structure/Size**




Plowing, cultivating, draining, liming, and manuring the land all affect the soil structure. For example, strongly acid and strongly alkaline soils tend to run together when wet and lose their structure. Good structure is most often found in soils that are near neutral in their reaction.

Adding organic matter to the soil is the main method by which a farmer can improve the structure and granulation of the soil. Organic matter not only binds soil particles together, but also lightens and expands the soil, making it porous and increasing its ability to absorb and hold water. Healthy plant roots also help greatly in improving the structure of soil.

### *Porosity*

Soil porosity is related to soil texture. The pore space of a soil is that portion of the soil occupied by air and water. The amount of pore space is determined by the structure and granulation of the soil particles. In sandy soil the pore spaces are large; in clay soils the pore spaces are more numerous and smaller. Good soils have 40 to 60 percent of their bulk taken up by pore space. Pore space may be filled with water or air.

In very sandy soil, the pore spaces are large. The result is that water moves through (or drains) faster. These soils dry quickly. On the other hand, a very clay soil may hold too much water. This causes roots to rot. In addition, water cannot penetrate the surface quickly. This causes water to run off and leads to a loss of soil through erosion.

Porosity is greatly benefited by organic matter, such as manures or compost. These materials increase the soil's water-holding capacity.

## *Water*

Soil water occurs in three forms: hygroscopic, capillary, and gravitational. The hygroscopic soil water is chemically bound to soil elements and cannot be taken up by the plant. Gravitational water is that which normally drains out of the pore spaces after rain. If drainage is too good, the capillary water runs out faster and plants suffer from drought.

Plants depend on the capillary water for their supply of moisture. The ability of the soil to hold and store water is of great importance to the gardener and the crops. Organic matter and good structure increase this supply of available water in the soil.

## *Soil pH*

Generally, in areas of heavy rainfall, soils can be assumed to be moderately to very acidic. The term "pH" is the method of expressing the amount of soil acidity or alkalinity. This is commonly known as the "sourness" or "sweetness" of the soil. The pH scale measures from 0 to 14. The 0 end of the scale is the acid end, and the 14 end of the scale is the alkaline end. A pH measurement of 7 is exactly neutral; that is, the soil is neither acid nor alkaline. A soil pH greater than 7 (say 8.5) is an alkaline soil. A soil pH less than 7 (say 6.0) is an acid soil. Most common vegetables, field crops, fruits, and flowers grow best on soils that have a pH of 6.5 to 7.0—in other words, a soil that is slightly acid to neutral.

Soil pH is important to the gardener because certain plant food cannot be taken up by the plant if the soil is too acid or too alkaline. In areas with much rain, soils are usually acid. The pH of acid soils can be raised by adding lime or wood ash.

After the farmer has determined the soil type, he or she can then determine the amount of limestone to apply to the land. Using the following chart, the farmer would first locate the soil type in the left-hand column, and then read across the row to the column in which the soil's pH falls. Assuming the soil type is clay loam and the pH level is 5, the farmer would need 1.5 tons of limestone to adjust the pH for 1 acre of soil.

**Table 2-1: Tons of Ground Limestone per Acre Needed to Raise pH**

| Soils of Warm Temperate and Tropical Regions | pH 3.5 to 4.5 | pH 4.5 to 5.5 | pH 5.5 to 6.5 |
|---|---|---|---|
| Sandy and loamy sand | 0.3 tons | 0.3 tons | 0.4 tons |
| Sandy loam | | 0.5 | 0.7 |
| Loam | | 0.8 | 1.0 |

| Soils of Warm Temperate and Tropical Regions | pH 3.5 to 4.5 | pH 4.5 to 5.5 | pH 5.5 to 6.5 |
|---|---|---|---|
| Silt loam | 1.2 | 1.4 | |
| Clay loam | | 1.5 | 2.0 |
| Muck | 2.5 | 3.3 | 3.8 |

## Soil Testing

A farmer can tell much about soil texture by simply feeling the soil. It is usually helpful to wet the samples before feeling them. By rubbing a damp soil sample between the thumb and fingers, a farmer can get a good idea of how much sand, silt, and clay are in the soil. Clay feels sticky and can be rolled very thin. Sand feels gritty, and silt has a smooth, floury, or powdery feel. (See the Soil Texture Key—http://sfec.cfans.umn.edu/prod/groups/cfans/@pub/@cfans/@sfec/documents/article/cfans_article_360665.pdf—from the University of Minnesota to learn more about the "feel method.")

An accurate method of determining the texture of soil is by mechanical analysis, using the "settling jar method." This method is simple and requires no special materials:

1. You will need a quart jar (clean, clear, smooth glass) a millimeter ruler, a soil sample, and water softener.

2. Prepare an 8% water softener solution. This is done by adding 6 tablespoons of water softener to 1 quart of water and shaking well.

3. To obtain a soil sample, scrape away the top few inches of debris from any area of ground. Dig a core of dirt from the first 6 inches and run the soil through a 1/8-inch mesh sifter. This is your soil sample.

4. Place 1/2 cup of your soil sample in the quart jar. Add 5 tablespoons of the 8% water softener solution. Add 3 1/2 cups of water. Close the jar and shake for 5 minutes.

5. Place the jar on a level surface and let stand for 40 seconds. Measure the depth of the settled soil with a ruler. It is important to measure in millimeters because it is more precise, and saves you the job of mathematical conversion when it comes time to work on the percentages. This first layer to be measured is the sand layer.

6. At the end of 30 minutes, measure the depth of the settled soil again; subtract the depth of your sand layer from this second measurement to obtain the depth of the silt layer.

## Elements Required for Plant Growth

There are 13 essential nutrients that come from the soil for a healthy plant. These nutrients are divided into two groups: macronutrients and micronutrients. Healthy plants require a greater amount of macronutrients than micronutrients. There are six macronutrients: nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S). Macronutrients are divided further into primary (N, P, and K) and secondary macronutrients (Ca, Mg, and S). The three primary macronutrients are typically found in bagged fertilizers. The essential micronutrients are boron (B), chloride (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), and zinc (Zn).

**Table 2-2: Macro- and Micronutrients**

| Macronutrients | Micronutrients |
|---|---|
| *Primary*<br><br>Nitrogen (N)<br>Phosphorous (P)<br>Potassium (K) | Boron (B)<br>Chloride (Cl)<br>Copper (Cu)<br>Iron (Fe)<br>Manganese (Mn)<br>Molybdenum (Mo)<br>Zinc (Zn) |
| *Secondary*<br><br>Calcium (Ca)<br>Magnesium (Mg)<br>Sulfur (S) | |

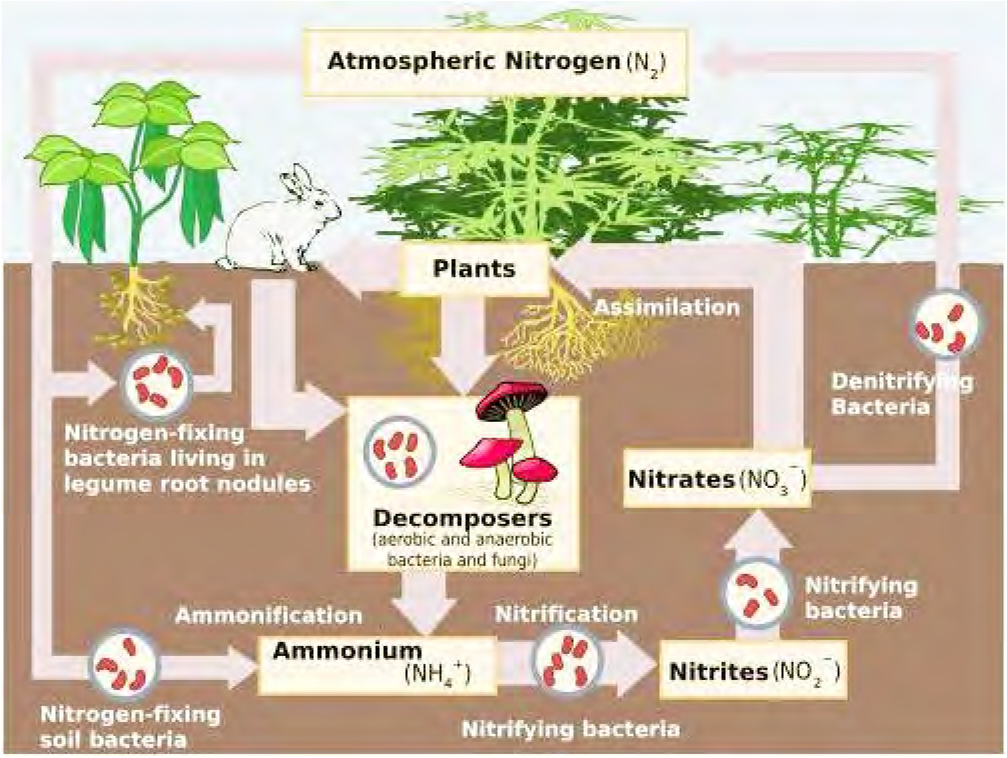
Nitrogen is one of the most important elements in the soil. When there is too much or too little nitrogen in the soil, productivity declines. There must be a continual renewal of nitrogen, because this nutrient is essential for plant growth and is always being removed from the soil by crops, rain, and other natural processes.

Nitrogen is directly responsible for the leaf and stem growth of plants. When nitrogen is available in the right amounts, plants grow strong and mature quickly. With the right amount of nitrogen, plants have a rich, green color. When plants are starving for nitrogen, their green color becomes pale, or even yellow in severe cases.

Too much nitrogen can cause as much harm as too little. An excess of nitrogen usually occurs when concentrated inorganic forms of nitrogen fertilizers are used. Although these types of fertilizers cause the plant to make fast, lush, watery growth, the plants are typically more susceptible to disease and insects. This type of unbalanced growth results when the excess nitrogen displaces other nutrients the plants need.

**Figure 2-2: Nitrogen Cycle**

Photo c/o creativecommons.org




Forms of nitrogen fertilizers (such as animal manures, peanut shells, leaves) feed nitrogen to the plants slowly over a longer period, providing more balanced and resistant plant growth. Nitrogen in organic matter is released by the action of soil microbes (small bacteria and molds that cannot be seen without a microscope). As soil microbes cause organic matter to decay, nitrogen is released in a form that can be taken in by plant roots.

The following chart lists organic materials and their nitrogen values. The farmer should use this chart as a guide when searching for nitrogen-rich values for composting or fertilizing.

**Table 2-3: Nitrogen Content of Organic Materials**

| Material | % Nitrogen | Material | % Nitrogen |
|---|---|---|---|
| Heated bone meal | 1.5 | Fresh crabs | 4.6 |
| Raw bone meal | 3.3 to 4.1 | Dried ground crabs | 10.0 |
| Steamed bone meal | 1.6 to 2.5 | Dried shrimp heads | 7.8 |
| Cottonseed meal | 7.0 | Lobster wastes | 2.9 |
| Corn fodder | 0.49 | Mussels | 1.0 |
| Oats, green fodder | 0.49 | Shrimp waste | 2.9 |

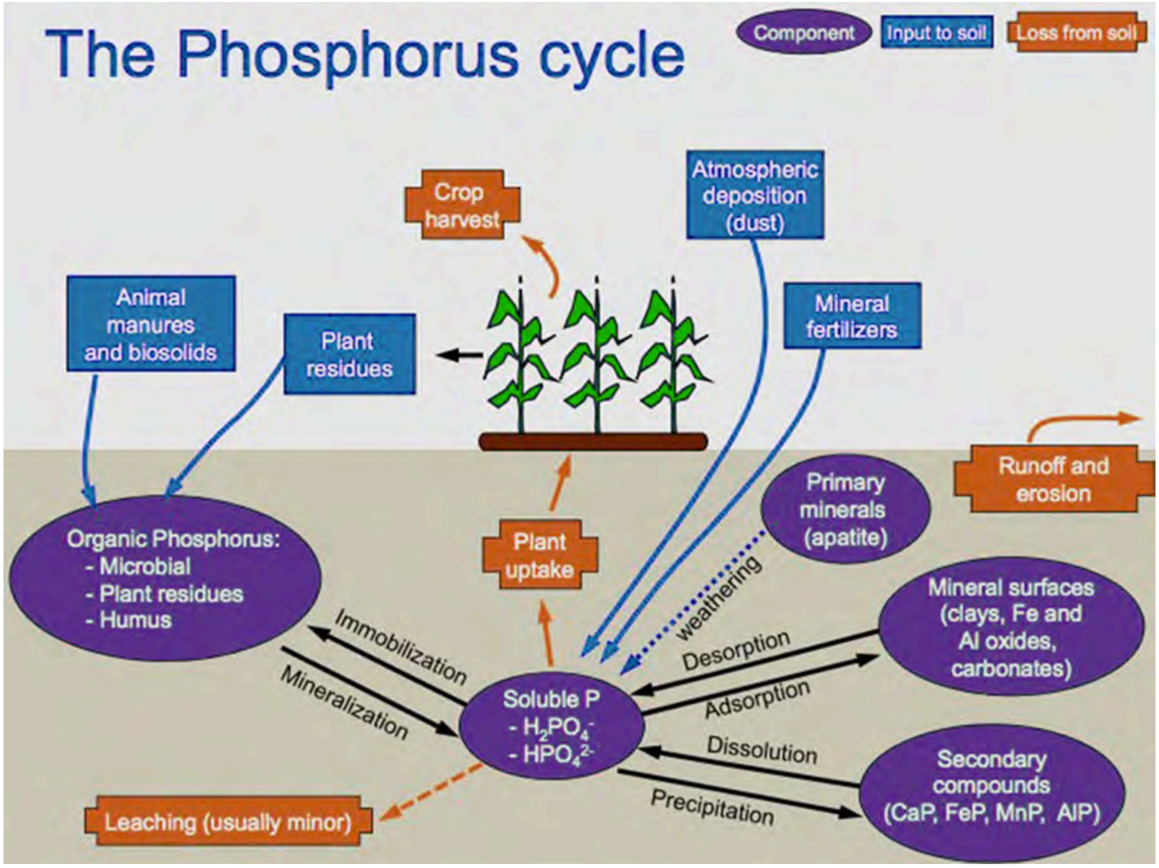
| Material | % Nitrogen | Material | % Nitrogen |
|---|---|---|---|
| Corn silage | 0.42 | Dried ground fish | 8.0 |
| Gluten meal | 6.4 | Acid fish scrap | 4.0 to 6.5 |
| Wheat bran | 2.3 | Oyster shells | 0.36 |
| Wheat middlings | 2.7 | Milk | 0.5 |
| Wheat meal | 9.0 to 11.0 | Wool wastes | 3.5 to 6.0 |
| Bone tankage | 3.0 to 10.0 | Beet wastes | 0.4 |
| Cattle manure, fresh | 0.29 | Brewery wastes | 1.0 |
| Cattle manure, urine | 0.58 | Castor pomace | 4.0 to 6.6 |
| Hen manure, fresh | 1.63 | Cattail reeds | 2.0 |
| Dog manure | 2.0 | Cocoa shell dust | 1.0 |
| Horse manure, solid fresh | 0.44 | Cocoa wastes | 2.7 |
| Horse manure, fresh urine | 1.55 | Grape pomace | 1.0 |
| Human excrement, solid | 1.0 | Green cowpeas | 0.4 |
| Human urine | 0.6 | Nutshells | 2.5 |
| Night soil | 0.8 | Peanut shells | 3.6 |
| Sheep manure, solid fresh | 0.55 | Peanut shell ashes | 0.8 |
| Sheep, fresh urine | 1.95 | Potato skins | 0.6 |
| Stable manure, mixed | 0.50 | Sugar waste | 2.0 |
| Swine manure, solid fresh | 0.60 | Tea grounds | 4.1 |
| Swine, fresh urine | 0.43 | Coffee waste | 2.0 |
| Sewage sludge | 1.7 to 2.26 | Tobacco stems | 2.5 to 3.7 |
| Bat manure | 6.0 to 10.0 | Corn stalks | 0.75 |
| Eggshells | 1.0 | Alfalfa | 0.24 |
| Dried blood | 10.0 to 14.0 | Cowpea hay | 3.0 |
| Feathers | 15.3 | Pea hay | 1.5 to 2.5 |
| Dried jellyfish | 4.6 | Soybean | 1.5 to 3.0 |

## Phosphorous

The second of the three primary macronutrients is phosphorus, which is essential for healthy growth, root development, fruit formation/growth, and resistance to disease. The diagram below explains the complex pathways of the soil phosphorus cycle.

**Figure 2-3: Phosphorus Cycle**

Photo c/o creativecommons.org




The phosphorus cycle begins with rocks. Rain causes the weathering of rocks, as well as the distribution of phosphorus throughout soils and water. Although phosphorus moves quickly through plants and animals in its inorganic form—the only form available to plants—it moves very slowly through soils. Unlike other biogeochemical processes, the phosphorus cycle does not include a gas cycle. Plants take up inorganic phosphorus from the soil, which is transferred to herbivores when they eat the plants, and to carnivores when they eat the herbivores. Organic phosphorus is returned to the soil when animals die or excrete, but then must be converted back to inorganic phosphorus for plant uptake, a process that occurs through bacterial decomposition.

In the following chart, the farmer can see that many locally available materials can supply phosphorus.

**Table 2-4: Organic Sources of Phosphorous**

| Material | % Phosphoric Acid | Material | % Phosphoric Acid |
|---|---|---|---|
| Bone meal, raw | 22.0 to 25.0 | Cow manure, fresh | 0.25 |
| Steamed bone meal | 30.0 | Cow manure, dried | 1.0 |
| Bone meal, heated | 30.0 | Wood ashes | 1.0 to 2.0 |
| Shrimp waste, dried | 10.0 | Peapod ashes | 3.0 |
| Dried ground fish | 7.0 | Banana trash ashes | 2.3 to 3.3 |
| Lobster refuse | 3.5 | Citrus waste, orange skins, ashed | 3.0 |
| Bat manure | 10.0 | Dried blood | 1.0 to 5.0 |
| Tankage | 2.0 | Hoof and horn meal | 2.0 |
| Wool wastes | 2.0 to 4.0 | Cotton seed meal | 2.0 to 3.0 |
| Raw sugar wastes (filter press) | 8.0 | Cocoa wastes | 1.5 |
| Castor pomace | 1.0 to 2.0 | Goat and sheep manures, fresh | 1.0 to 1.6 |
| Poultry manure, fresh | 1.0 to 1.5 | Goat and sheep manures, dried | 1.0 to 1.9 |
| Poultry manure, dried | 1.5 to 2.0 | Horse manure, fresh | 0.35 |
| Hog manure, fresh | 0.45 | Horse manure, dried | 1.0 |

## Potassium

The third of the macronutrients is potassium, also known as potash. It is essential for the development of strong plants. Plants starving for potassium do not resist heat. They are not disease resistant. Signs of weak stems may indicate a need for potassium.

The following table lists natural organic sources of potassium. The farmer can make good use of this chart to find materials that will return potassium to the soil.

**Table 2-5: Natural Sources of Potassium**

| Material | % Potash | Material | % Potash |
|---|---|---|---|
| Wood ashes | 10.0 | Cow manure, fresh | 0.1 |
| Molasses waste | 3.0 to 4.0 | Cow manure, dried | 1.5 |
| Tobacco stems | 4.5 to 7.0 | Cow manure, urine | 0.5 |
| Garbage | 2.3 to 4.3 | Horse manure, fresh | 0.3 |
| Water lily stems | 3.4 | Horse manure, dried | 1.6 |
| Cocoa shell residue | 2.6 | Horse manure, urine | 1.5 |

| Material | % Potash | Material | % Potash |
|---|---|---|---|
| Dried potato vines | 1.6 | Goat and sheep manure, fresh | 0.3 |
| Vegetable waste | 1.4 | Goat and sheep manure, dried | 3.0 |
| Castor pomace | 1.0 to 2.0 | Goat and sheep manure, urine | 2.3 |
| Beef wastes | 0.7 to 4.1 | Chicken manure, fresh | 0.6 to 1.0 |
| Wool waste | 1.0 to 3.5 | Chicken manure, dried | 1.2 |
| Alfalfa hay | 2.1 | Banana trash, ashed | 41.0 to 50.0 |
| Cowpea hay | 2.3 | Peapods, ashed | 27.0 |
| Soybean hay | 1.2 to 2.3 | Hog manure, fresh | 0.5 |
| Weeds | 0.7 | | |
| Potato tubers | 2.5 | | |

**Table 2-6: Percentage Composition of Various Materials (Nitrogen, Phosphorous, and Potassium)**

| Material | % Nitrogen | % Phosphorous | % Potash |
|---|---|---|---|
| Banana skins (ash) | 3.25 | 41.76 | 0 |
| Banana stalk (ash) | 2.34 | 49. | 4 0 |
| Bat guano | 1.0 to 12.0 | 2.5 to 16.0 | 0 |
| Brewers grains (wet) | 0.90 | 0.50 | 0.05 |
| Castor bean pomace | 5.0 to 6.0 | 2.0 to 2.5 | 1.0 to 1.2 |
| Cattail reed and stems of water lily | 2.02 | 0.81 | 3.43 |
| Cocoa shell dust | 1.04 | 1.49 | 2.71 |
| Coffee grounds | 2.08 | 0.32 | 0.28 |
| Coffee grounds (dried) | 1.99 | 0.36 | 0.67 |
| Corncobs (ground, charred) | 0 | 0 | 2.01 |
| Corncobs (ash) | 0 | 0 | 50.0 |
| Common crab | 1.95 | 3.60 | 0.2 |
| Cow peas (green forage) | 0.45 | 0.12 | 0.45 |
| Cow peas (seed) | 3.10 | 1.0 | 1.2 |
| Cucumber skins (ash) | 1 | 1.28 | 27.2 |
| Dried jellyfish | 4.6 | 0 | 0 |
| Duck manure (fresh) | 1.12 | 1.44 | 0.49 |
| Egg shells, burned | 0 | 0.43 | 0.29 |
| Eggshells | 1.19 | 0.38 | 0.14 |
| Feathers | 15.3 0 | 0 | |
| Field beans (seed) | 4.0 | 1.20 | 1.3 |
| Field bean (shells) | 1.7 | 0.30 | 0.35 |

| Material | % Nitrogen | % Phosphorous | % Potash |
|---|---|---|---|
| Fire pit ashes | 0 | 0 | 4.96 |
| Fish scrap (fresh) | 2.0 to 7.5 | 1.5 to 6.0 | |
| Freshwater mud | 1.37 | 0.26 | 0.22 |
| Garbage, rubbish | 3.4 to 3.7 | 0.1 to 3.7 | 2.25 to 4.25 |
| Hair | 12.0 to 16.0 | 0 | 0 |
| Hoof meal and horn dust | 10.0 to 15.0 | 1.5 to 2.0 | 0 |
| Leather, ground | 10.0 to 12.0 | 0 | 0 |
| Lobster refuse | 4.3 | 3.5 | 0 |
| Lobster shells | 4.6 | 3.52 | 0 |
| Molasses residue in manufacture of alcohol | 0.70 | 0 | 5.32 |
| Orange skins (ash) | 0 | 2.9 | 27.0 |
| Peanut shells | 0.80 | 0.15 | 0.5 |
| Pigeon manure (fresh) | 4.19 | 2.24 | 1.41 |
| Pumpkin seeds | 0.87 | 0.50 | 0.45 |
| Residue from raw sugar | 1.14 | 8.33 | 0 |
| Salt marsh hay | 1.10 | 0.25 | 0.75 |
| Tea grounds | 4.15 | 0.62 | 0.4 |
| Tobacco leaves | 4.0 | 0.5 | 6.0 |
| Tobacco stalks | 3.7 | 0.65 | 4.5 |
| Waste from rabbits | 7.0 | 1.7 to 3.1 | 0.6 |

## Other Minerals

The remaining essential nutrients are important to plant growth. In fact, plants will not grow healthily if even just one nutrient is missing. Farmers usually depend on the soil to supply these minerals. By applying compost, organic matter, and inorganic fertilizers to the soil, the farmer can be assured of supplying the plants with all their mineral needs.

## Soil Microbes and the Soil Workshop

Soil microbes are tiny living plants and animals that cannot be seen by the naked eye. They are best seen under a microscope. Without these soil microbes, agriculture could not exist.

We can imagine that the soil is a workshop for soil microbes. Within a soil, there are many different kinds and groups of microbes, each performing a special job in the soil's workshop. The operations of all types of soil microbes are necessary to support healthy plant life. The work of soil microbes is the basis of agricultural productivity. Soil microbes work in many ways. Some break down complex organic matter into foods that plants can use. Microbes that bring about the decay of organic matter are most familiar. For example, when plants or animals die, their bodies—by the work of microbes—fall apart and give back to the soil and air most of the elements taken from these sources for life. These elements are then used as food for other forms of life. This is known as the life cycle. Life is supported in a continuous cycle.

Other helpful soil microbes capture nitrogen from the air and change it into food for plants. Some microbes, called nitrobactia, change certain nitrogen materials of the soil into forms easily used by plants. Other microbes store nitrogen surpluses, and then release them slowly, as needed by the plants. There are even microbes (predaceous fungi) that attack and eat nematodes (small worms that eat plant roots). These microbes are only found in soils with humus. Health-producing vitamins and disease-fighting antibiotics are produced by microbes and plants in a healthy soil.

The skilled gardener can learn to judge if the soil's microbes are healthy or not. One way to do this is by the smell of the soil. A healthy soil microbe population will give the soil a satisfying smell that is not found in badly eroded or depleted soils. If earthworms are abundant in soil, one is assured that the soil microbes are present and healthy. More experienced farmers can detect their presence by the spongy feel of a good soil.

Soil microbes multiply at a fast rate whenever the right kinds of foods are available to them. Practically all of the beneficial soil microbes feed on organic matter in one form or other. By building up the organic matter and humus of the soil and applying commercial fertilizers, the farmer and nature join hands to produce abundant healthy food. The more skill the farmer develops in handling the organic materials, the more service he or she will get from the soil microbes.

A soil management and improvement program is essential to every farm if the farm is to remain a viable food-producing unit for decades to come. When the farmer takes steps to maintain and improve the soil's fertility, he or she is truly building a heritage for the family and the country.

## Organic Matter in Soil Management

In developing a soil management program, the farmer must first assess the soil's fertility and general condition (such as structure, texture, pH, and erosion potential). Then the farmer should decide which crops can be grown and are best suited to the farm's climate, slope, and soil conditions. The farmer should then search out all locally available materials that can be used for fertilizers, mulches, and general soil building. Examples of these materials are animal manures (such as chicken, horse, cow, rabbit, pig, donkey, goat, and bat), wood ashes, banana trash, sawdust, filter press mud, bamboo leaf trash, grass, garbage scraps, and any other organic waste materials. The farmer should also learn the price of all commercial bag fertilizers that are available. All these materials are the food for the soil and crops.

One of the important aspects of soil fertility and structure in the tropics is the soil organic matter. With the increased heat and moisture in the tropics, soil organic matter decays and is quickly utilized by plants. Organic matter is the term used when speaking of any plant or animal matter. Useful organic matter includes all animal manures, all plant materials, and organic waste materials such as cannery wastes, sawdust, and citrus peels. All these materials and many more can be very useful to the farmer in building and maintaining the soil's fertility.

Organic matter is life for the soil, the storehouse of the soil's nutrients. When properly handled and applied to the land, organic matter improves the texture and structure of the soil. It increases the soil's ability to hold water, stimulates beneficial soil organisms, suppresses disease organisms, and makes nutrients available to the plants.

When forestland is newly cleared and cultivated, good crops can often be produced for the first few years with little or no fertilizer. Then, as the land grows "older," more and more fertilizers are needed to produce an adequate crop. This happens because the natural fertility of the land, in the form of organic matter and humus, is depleted but not replaced. By observing and applying nature's fertility cycle, the farmer can maintain soil fertility and produce significant yields. Observing the forest, which grows very well without any fertilizer, one might ask, "How is it so?" In the forest, the roots of the trees and plants gather nutrients from shallow and deep places in the soil and send them to the leaves of the trees or plants. When the leaves and branches die and fall to the ground, they decay and rot, releasing nutrients to the soil to be used again by the plants. This is the natural life cycle.

The lesson is that anything that will rot and decay is potential and necessary plant food. Certain materials, such as animal manure, which rot and decompose quickly and release their nutrients to the soil quickly, are especially useful to the farmer. However, anything that will rot, from corncobs to newspapers, will improve the fertility of the soil. The key point is that organic matter must be decomposed before the nutrients are released for use by the plants.

A farmer's fertilizer program must provide all the nutrients needed for plant growth in a balanced form. Many of the nutrients will already be in the soil. The farmer does not have to add all the nutrients, but he or she must be sure that they are available to the crop. This can usually be done by correcting the soil pH and by replenishing the soil organic matter.

## Organic Fertilizers

In this manual, we have divided fertilizers into three groups: organic fertilizers, inorganic fertilizers, and composts.

As explained earlier in the manual, organic matter is any plant or animal material. Organic fertilizers are those types of organic matter that are best suited for the fertilization of crops. Actually, anything that will decay will provide nutrients for plants, but materials that decay quickly and release their nutrients are most commonly used.

It is generally recognized that the most important fertilizer elements for plant growth are nitrogen, phosphorous, and potassium. Many of the other essential elements are also present in organic fertilizers, but the best basis for determining the quality of animal manures and other organic fertilizers is the amount of nitrogen, phosphorous, and potassium present in them.

## Animal Manures

Animal manures are the most commonly used organic fertilizers. Many break down very quickly, which makes them even more valuable as fertilizers for crops. When properly collected, stored, and used, animal manures can return much fertility to the land.

With most animals, such as goats, cows, and donkeys, about half the manure is dropped in fields or uncultivated land and therefore lost for most practical purposes. The real potential is where many animals are confined to a small area for a period. Rabbits, chickens, goats, pigs, horses, and cows in pens, stables, and dairies provide manure that builds up and can be easily collected.

To be valuable to soil, manure needs to be "protected." When manure is allowed to build up in an area but is exposed to rain and sun, much of the plant nutrients are lost. In fact, if it is allowed to stand in small, scattered piles in an open yard, exposed to rain and sun, it will lose more than half of its fertilizer value. This loss occurs mainly in the form of leaching, which is caused by rainwater dissolving precious nutrients and washing them away. When manure is allowed to dry out, nitrogen in the manure becomes a vapor and is lost in the air. Whenever the smell of ammonia is noticed around a manure pile or stable, this is a sure sign that nitrogen is escaping to the air. Such an odor is an undeniable symptom of wasted plant nutrition.

An important part of animal waste is the urine or liquids, which are richer in plant nutrients than the solids. Whenever possible, efforts should be made to conserve the urine. This is usually done by providing some sort of bedding in the pen or cage that will absorb and hold the liquid. Materials commonly used for this purpose are sawdust, wood shavings, straw, cut grass, or bagasse (the fibrous waste material produced after crushing sugarcane or sorghum stalks to extract their juice).

Stored manure should be placed in a watertight pit or container. For the market gardener, we suggest 55-gallon drums (with covers) for the storage of both manures and inorganic fertilizers. If manures must be stored in the open, they should be heaped in a pile on a level surface with a clay base to prevent the loss of nutrient-rich liquids. The pile should also be covered with a layer of soil if it is to sit for a long period. The soil cover conserves moisture in the heap and prevents gases from escaping.

The best method of dealing with large quantities of manures is to compost them. If the manure cannot be composted, it should be spread and worked into land quickly to conserve as many of the nutrients as possible. Spreading manure and leaving it on the surface of the soil is wasteful. On hilly or sloping land, rain will wash most of the nutrients away. It is wise for the small farmer to hoe or fork the manure into the soil. If a power hand tractor is available, it can be used very effectively. Any method may be used; the important thing is to get the manure into the soil. The chart below shows which manures are highest in fertilizer value. Animal manures also add valuable trace nutrients and organic matter to the soil, improving the soil's texture, fertility, and structure and promoting general plant growth.

**Table 3-1: Approximate N-P-K Values of Different Manures**

| Manures | % Nitrogen | % Phosphate | % Potash |
|---|---|---|---|
| Rabbit | 2.4 | 1.4 | 0.6 |
| Hen | 1.1 | 0.8 | 0.5 |
| Sheep | 0.7 | 0.3 | 0.1 |
| Steer | 0.7 | 0.3 | 0.4 |
| Horse | 0.7 | 0.3 | 0.6 |

| Manures | % Nitrogen | % Phosphate | % Potash |
|---|---|---|---|
| Duck | 0.6 | 1.4 | 0.5 |
| Cow | 0.6 | 0.2 | 0.5 |
| Pig | 5.0 | 3.0 | 0.5 |
| Bat | 1.0 to 12.0 | 2.5 to 16.0 | 0 |

To make the best use of manures and other organic fertilizers, the farmer should try to combine the manures with other materials to obtain a completely balanced fertilizer. This will produce healthy, balanced plant growth and greater resistance to disease and insects. When a fertilizer or manure very high in nitrogen is used alone or in an unbalanced mixture, the plants will suffer. For example, if too much readily available nitrogen is in the soil, the plants will show signs of burning; if there is much nitrogen and not enough of the other nutrients, fast but weak leaf growth will occur. This type of growth is very watery and is susceptible to insect and disease attack. When the plant does not have balanced nutrients, it develops more sugar and starches, and less protein. Because insects prefer sugars and starches, the plants are attacked more often when such unbalanced growth occurs. A balanced program of manure application helps avoid unhealthy plants. **It is important to apply the right amounts and mixture of manures.[1] As you will see below, different manures have different nutrient contents that affect how they should be applied.[2] Soil, environmental, and agronomic conditions (such as pH, soil composition, rainfall amounts, temperatures, and plant variety) also affect how one should apply manure. It is best to consult with a local extension agent or your associate Peace Corps director (APCD) to come up with a well-balanced approach.**

**Table 3-2: Approximate Annual Excrement of Useful Manure that could be Collected and Used by the Soil in any Year**

| Animal | Total Excrement Pounds | Solid Pounds | Liquid Pounds |
|---|---|---|---|
| Horse | 18,000 | 14,400 | 3,300 |
| Cow | 27,000 | 19,000 | 3,000 |
| Pig | 30,500 | 18,300 | 12,200 |
| Sheep | 12,000 | 8,300 | 4,200 |
| Hen | 8,500 | | |

1 In places where a soil testing service is available and farmers have access to large amounts of manure, they should get their soil tested in order to be able to determine the correct amount of N, P, and K (in whatever form) to add. Most communities where Peace Corps Volunteers are placed, particularly in Sub-Saharan Africa, may not have access to such a service or have large amounts of manure to use. The amounts that are recommended in the text are based on soil that is in continuous production and on the amount of N-P-K that is removed from the soil and needs to be replaced under different culture conditions, that is, intensive (market garden) vs. semi-intensive (home garden).

2 The application rates for rabbit, chicken, and cow manure vary, depending on soil composition and environmental conditions, as well as on the choice of crops to be grown.

### *Chicken Manure*

Chicken manure is usually used at the rate of 2 tons per acre for intensive market gardeners using raised beds. One should apply 15 to 20 pounds of chicken manure per 100 square feet of bed. Chicken manure is low in phosphorous and potassium, so it should be used with other organic or inorganic fertilizers that supply those two nutrients. An example of such a combination is 10 pounds of chicken manure and 8 pounds of filter press mud, and 5 pounds of fresh wood ash. Filter press, the waste material from sugar factories, is very high in phosphorous. Wood ash supplies potash. This combination, or a similar mixture, forms a balanced fertilizer. Chicken manure alone can be used on leaf crops such as Chinese cabbage and Swiss chard, but when used alone for fruit crops such as tomatoes and peppers, the plants produce more leaves and less fruit. When using raw or fresh chicken manure, one part ground limestone to six parts chicken manure should be mixed to help conserve nitrogen and mellow the manure.

A portable chicken roost can be very helpful to the intensive market gardener. The roost can be made from fairly cheap materials such as wood or bamboo, and covered with chicken (mesh) wire. The floor is also covered with mesh wire. The portable roost is made just the right width (5 feet) to fit a raised bed. The roost is placed on the bed as soon as the crop is reaped. As the chickens eat the remaining weeds, insects, and crop waste, they fertilize the soil with their manure. The roosts can house from 10 to 15 layers or 40 to 50 broilers, which will add 10 to 15 pounds of manure to the soil every few weeks. The roosts should be moved to a new bed every two to three weeks to avoid over-fertilization. The farmer benefits from this setup by saving money on feed, fertilizers, and insecticides.

**Figure 3-1: Portable Chicken Roost and Egg-laying House**

Photo c/o creativecommons.org

Because the chickens eat weeds, weed seeds, insects, and crop or garden waste, fewer bag feeds are required for proper growth. Their manure also fertilizes the soil, so fewer fertilizers are needed. The overall health of the garden is increased, because there are fewer insects and weed seeds, and crop waste is used so none is allowed to pile up and attract disease and insects.

The farmer can intensify the land and build the soil to produce more vegetables and meat by this simple method.

### *Horse Manure*

This type of manure is considered a "hot" manure. Horse manure breaks down very fast and releases nutrients quickly. When used in large amounts, it can cause burning of the plants. Fresh horse manure should be mixed into the soil or placed in planting holes, covered, and allowed to cure in the soil for 10 to 14 days before planting.

Bedding such as rice hulls, sawdust, or hay used in horse stables will increase the value of the manure. The bedding absorbs and holds the nitrogen-rich liquid portion of the manure. Because horse manure rots quickly, two-month-old manure can be used right before or at planting time. Looking at the manure chart, we can see that horse manure is low in phosphorous and potassium (as are most animal manures). These manures should be combined and used with manures and materials that supply phosphorous and potassium, such as bat manure, filter press mud, composted banana trash, rabbit or chicken manure, wood ash, citrus waste, fish trash, lobster trash, shrimp trash, dried blood, butcher wastes, and cocoa shell waste. In this manual, we have provided a chart that gives the fertilizer value of these and many more organic materials. Remember that these materials must decompose before their nutrients are available to the plant.

On field crops such as corn or pumpkin, horse manure should be used at the rate of 5 tons per acre. For intensive raised beds, 1 to 3 cubic yards of horse manure plus 5 pounds of chicken manure, 5 pounds of wood ash, and 5 pounds of filter press or bat manure should provide a balanced fertilizer for 100 square feet of bed. For less intensive vegetable crops, 25 pounds of horse manure plus 10 pounds of filter press should be applied for 100 square feet of garden space.

### *Sheep Manure*

Sheep manure is also considered a "hot" manure and should be used in the same amounts and mixtures as horse manure.

### *Cow Manure*

This manure is usually called a "cold" manure because it takes longer to decompose and release its nutrients. Cow manure can be used in larger quantities than horse and sheep manure, but it must be well rotted. Cow manure is an excellent soil conditioner for improving the texture and structure of the soil. If fresh manure is used, it should be applied to the land two months before planting. As with most animal manures, phosphorous and potash should be added, in the form of either inorganic fertilizers or other manures and organic fertilizers. The recommended rate is 10 to 15 tons of cow manure per acre. Cow manure is very valuable as a soil texturizer, and should be used for this purpose at the rate of 1 to 2 cubic applications per 100 square feet of raised bed.

### *Rabbit Manure*

Rabbit manure is one of the finest manures for vegetable production. It is high in nitrogen and phosphorous, but decomposes slowly. Because rabbit manure is "colder" than chicken manure, it can be used in large quantities, and can be used fresh on most crops except root crops.

Rabbit cages with mesh wire floors are very practical, because the manure pile can be cared for right where the manure falls. Litter such as sawdust will absorb the liquid part and help the manure pile cure. Some farmers dig beds under the cages and supply the bed with earthworms. The earthworms thrive on the rabbit manure, composting it into an odorless and very valuable plant food. In this system the earthworms multiply greatly. They can be transferred to the garden to do their soil improving work there, or they can be sold to other gardeners.

For intensive raised beds, 40 to 50 pounds of rabbit manure plus 3 to 4 pounds of wood ash per 100 square feet should provide enough nutrients. In less intensive cultivation, such as row crops, 25 to 30 pounds per 100 square feet will supply a great portion of the needed nutrients. Rabbit manure also gives good results when placed in planting holes for tomatoes or watermelons. Two quarts of rabbit manure partly mixed with the soil in the planting hole should provide adequate nutrients throughout the growing season.

### *Bat Manure*

Bat manure is often found in large amounts in caves, and is a very valuable fertilizer. It is usually very rich in nitrogen and especially high in phosphorous. The most important use of this manure is as a source of phosphorous for crops. It is also useful for mixing with manures that are low in phosphorous. Bat manure has no potassium, so this nutrient must be supplied. Wood ash is a good source of potash.

Where bat manure has been protected from rain and water, it can be used in amounts very close to the recommended amounts of inorganic fertilizers.

Compared with inorganic fertilizers, animal manures are usually lower in nitrogen, phosphorous, and potash, but the manures replenish the soil's organic matter and improve the structure, also increasing the beneficial soil microbes. Highly soluble inorganic fertilizers—that is, fast-acting fertilizers—speed up the loss of organic matter in the soil. A soil with a good supply of organic matter and good sponge structure will make better use of inorganic fertilizers. The soil structure absorbs and holds nutrients that would otherwise wash through the soil or wash off of a heavy clay soil.

## Liquid Fertilizers

In vegetable growing, it is often very helpful to use a liquid fertilizer to give extra feeding to seedbeds, seedlings, and young transplants.

Manure can be used to make an effective liquid fertilizer, often called "manure tea." All that is done to make manure tea is to soak a portion of the manure in water for a time. This permits whatever soluble nutrients there are in the manure to leach into the water.

Any kind of manure can be used to make manure tea. Fresh manure can be used, but well-rotted manure is best. A good method requires the use of 55-gallon drums. A sugar sack or crocus bag is filled with a mixture of 1 part chicken manure, 1 part horse manure, and 1 part cow manure. The bag is then placed in the drum and covered with water. The bag may have to be weighted with a stone so it will stay completely underwater. A tight lid or cover is then placed on the drum and it is allowed to sit for two to four weeks. At the end of that time, the bag should be taken out and water added to the drum until it is full. The manure tea should be the color of regular drinking tea—or even lighter if it is to be used to water young seedlings. The tea can be used to water seedbeds, seedlings, new transplants, and other plants. The tea should be poured directly around the roots of the transplants at about 1 cup per plant.

**Figure 3-2: Making Manure Tea**

## *Organic Refuse as Fertilizers and Texturizers*

As mentioned earlier in the manual, the farmer should know where to obtain all locally available soil-building and fertilizing materials.

As with any organic fertilizer, organic refuse must decompose to release its nutrients. Some valuable organic refuse materials are bagasse, sawdust, filter press mud, citrus waste, and chicken feathers. The most valuable and available organic refuse fertilizer is filter press mud from sugar factories. This material has some nitrogen value, but is most valuable for its high phosphorous content. Filter press can be combined with animal manures to form a complete, balanced fertilizer.

Many organic materials must be composted before they are useful as crop fertilizers. When using materials such as sawdust or bagasse, they should either be composted or used as mulches on the surface of the soil. If large quantities of these materials are mixed into the soil, they will cause a nitrogen lock. This means that nitrogen will be taken from the soil and plants until the material is decomposed enough to release nutrients.

This happens because some materials require a lot of nitrogen for the microbes to decompose them. If a nitrogen lock is suspected in a garden or crop area, a nitrogen fertilizer such as chicken manure or sulfate of ammonia should be applied.

The market gardener should realize that all organic materials are potential fertilizers and soil builders. All sources of these materials should be utilized and conserved. With the correct application of properly prepared organic fertilizers and soil amendments, the land will eventually become more productive, fruitful, and easier to work.

## *Use of Inorganic Fertilizers*

Positive, sustainable impact and "do no harm" are core principles of Peace Corps development work that should provide a framework for every decision to promote and disseminate technologies or practices to improve local agriculture and food security. In considering whether or not to promote the use of inorganic fertilizers in smallholder agriculture, the answer may not always be clear. Under the right conditions, the right fertilizer can significantly increase productivity (*yield* or *value* of crop per unit area), particularly on poor and degraded soils. This result, in turn, can have a positive impact on the environment, reducing pressure to convert forests and other fragile lands to agricultural uses, increasing biomass production with the additional organic matter supplied, helping to retain soil nutrients and moisture, and helping to increase the soil organic matter content.

For most smallholder farmers in developing countries, however, use of any fertilizer is a complicated economic decision. Inorganic fertilizer can be an expensive investment. With few or no services available to test a farmer's soil, it is nearly impossible to determine what soil nutrients are lacking and what fertilizer would be most beneficial. And, even if known, the right fertilizers are often in limited supply or not available at all when application is optimal. There is the additional uncertainty of unstable costs (of inputs) and lack of guaranteed returns on investment. Additionally, negative environmental concerns add an ethical element to any decision. Production and transportation of the (often imported) nitrogen-based fertilizers requires non-renewable energy (from fossil fuels). Phosphorous is a finite resource in ever-greater demand and in supplies that will eventually be exhausted. Inorganic fertilizers, when overused or applied incorrectly, can enter surface and ground waters, contaminate potable water supplies, and lead to the enrichment of water bodies with chemicals. Likewise, there can also be a buildup in the soils of salts and heavy metals such as cadmium, as well as a release of nitrous oxide (N2O), a greenhouse gas, contributing to climate change.

For many developing countries where Peace Corps is engaged in food security work, the environmental costs of using inorganic fertilizers are not currently considered significant in light of the more immediate need for food. In Sub-Saharan Africa, where most of these activities are taking place, inorganic fertilizer use is very low, the average amount applied each year (10 kilograms per hectare or less) being well below what is needed to replace the nitrogen, phosphorous, and potassium that is removed with the harvests. Available supplies of animal manures and crop residues that can be used to organically fertilize and mulch fields are limited and very often well below what is needed to have a significant impact on production. Therefore, encouraging correct use of inorganic fertilizer, where and when feasible, can make sense. However, for efficient nutrient utilization, inorganic fertilizer should be used as part of a site-specific, integrated soil fertility management strategy that also includes 1) the use of organic matter (manures, compost, mulch, biochar, etc.); 2) water harvesting; and 3) control of soil erosion. These complementary activities will help ensure that maximum benefits are derived from each of the component practices, and that environmental risks are minimized.

## *Soil-improving Crops*

One method that a farmer can use to return organic matter to the soil and improve its fertility is to grow crops for plowing into the soil. These are known as green manure crops.

Legumes are a group of plants that produce pods, such as red peas, cow peas, broad beans, sugar beans, green beans and many others. These crops have a special microbe that grows on them. This special microbe has the power to take nitrogen (the most important fertilizer element) from the air and store it in nodules on the roots of the legume. This microbe also feeds nitrogen to the plant.

Air that we breathe is 80 percent nitrogen and 20 percent oxygen. So, the most important and scarcest plant nutrient is all around us in abundance.

**Figure 3-3: Roots of a Bean with Nodules**

Photo c/o creativecommons.org

The legumes and soil microbes are the only way the farmer can take advantage of this free source of nitrogen.

By planting a crop of legumes, allowing them to grow until just before they begin to flower, and then chopping them for compost or forking them into the soil, the farmer/gardener can add valuable nitrogen and organic matter to the soil. After they are plowed into the soil, one month must pass before crops can be planted. Even if the crop is allowed to mature and the peas are picked, the crop will still improve the soil and add some nitrogen if the roots and crop trash are returned to the soil.

A farmer's land should have a portion planted to green manure crops (legumes) at all times. This allows the farmer to rotate the crops and always be improving a portion of the land. Green manure crops are an excellent source of nitrogen-rich material for the compost pile.

## Inorganic Fertilizers

Inorganic fertilizers can be very valuable to the smallholder farmer, but when too much dependence is placed on them and the soil organic matter is neglected, trouble is sure to arise. As organic matter in the soil is depleted, more inorganic fertilizers are needed. This cycle can continue until great quantities of inorganics are required to produce crops from the lifeless soil. Then the farmer is caught in a vicious cycle of dependence on large quantities of high-cost fertilizers.

## *Use of Inorganic Fertilizers*

Inorganic fertilizers are made by a chemical process. The manufacture of these fertilizers requires large amounts of petroleum, so the price of inorganic fertilizers will always increase as the price of petroleum increases.

A complete fertilizer is one that contains a mixture of all three major fertilizer elements: nitrogen, phosphorous, and potassium. An example of a complete fertilizer is sulfate of ammonia, which is mostly nitrogen.

The numbers on a fertilizer bag tell a farmer the percentage of available nitrogen, phosphorus, and potassium. The available nitrogen is in the form of elemental nitrogen (N). Available phosphorus is in the form of phosphorus oxide (P2O5) and available potassium is in the form of potassium oxide (K2O). Reading from left to right on the bag, the first number always stands for nitrogen; the second number phosphorous and the third number is potassium. For example, a fertilizer bag marked 5–10–10, would mean that the mixture in the bag is 5 percent nitrogen, 10 percent phosphorous, and 10 percent potash.

A farmer provided with a soil test and an understanding of fertilizer grades will be able to select the fertilizer most suited to and needed by the soil. Sulfate of ammonia is a very soluble, high-potency nitrogen fertilizer. It is used as a "side dressing"[3] after the crop is growing. It is usually applied right before or in the early stages of fruiting. This gives the plant a boost when much energy is needed for fruit production. On other crops, such as cabbage and leaf crops, sulfate of ammonia is applied just before the cabbage begins to fold. Sulfate of ammonia can also be mixed with water at the rate of 2 to 3 tablespoons per gallon and used to water seedlings. This fertilizer is very potent and must be used with care, or plants can be injured.

Complete fertilizers should be placed in a furrow 3 inches deep and covered with soil, or broadcast on the surface and mixed into the top 3 to 4 inches of the soil.

**Figure 3-4: Fertilizer Bag with Grade Numbers** Photo c/o creativecommons.org


3 Side dressing is the practice of applying fertilizer to the soil on or around the side of the plant. This practice spurts growth during periods when nutrient demand is high in plants, such as during fruiting.

When fertilizing row crops with a complete fertilizer such as 5–10–10 or 6–18–27, one medium handful for every 3 feet of row length should be applied.

Check with your program officer, extension agent, or Ministry of Agriculture for guidance on the use of inorganic fertilizers.

### *Fertilizer Application*

Fertilizer placement is an important aspect of farming. Many farmers broadcast the fertilizer on the soil surface. This is a very wasteful method. Rain and sun will rob the manures or fertilizers of their nutrients except where the soil is very sandy. The best method is to incorporate or mix the manure, compost, or inorganic fertilizer into the soil. This method, although it requires more time, labor, and skill, is by far the best method. Mixing the fertilizers with the soil places the nutrients where the plant needs them most: around the roots. In the soil, the nutrients are also protected from the sun and washing rains. In these days of fertilizer shortages, the farmer must learn to use resources and soil fertility with skill and wisdom.

Fertilizers and compost can be placed in the earth in a few ways. The most common method is "forking" or mixing it in with a fork or spade. When using this method, care must be taken to use the correct amount mixed thoroughly and distributed evenly throughout the soil area. Pockets or lumps of fertilizer in the soil can burn plant roots and damage plant growth. Power hand tractors, disc harrowing, or rotation can be used to perform the task. Portable, highly mobile power hand tractors are very useful to smallholder hillside farmers.

Another method commonly used is to dig "planting" holes where the transplants will be planted and place manure or fertilizers in the holes, then filling the holes with soil. Very good results are obtained if this method is done correctly. With this method, a large amount of manure or mixture of manure and inorganic fertilizer can be placed in the bottom of the hole. This gives the plant abundant feeding throughout its life. The trick is to dig the hole deep enough—10 to 18 inches is a good depth—and then fill the hole with manure up to about 6 inches from the soil surface. Always provide 4 inches of soil between the transplant's roots and the fertilizer. The distance can be less if compost or well-rotted manure mixed with soil is used.

Another method of fertilizer placement is to open a furrow with a plow or hoe and then place the manure or fertilizer in the shallow trench. Then the furrow is pulled back over the fertilizer, covering it about 3 to 4 inches deep.

When manure and foods are placed beneath the plant, the plant's roots grow deep into the soil to the source of food. These plants are protected in times of drought because of their deep roots. When fertilizers and nutrients are placed on the soil surface, the plants roots tend to grow shallow, near the surface of the soil.

## Composting

Composting is any system of mixing and decaying natural wastes (manure, garbage, etc.) in a pile or pit, so as to obtain a product resembling what the forest makes on its floor. Compost is very rich in humus. Humus is the final state of decomposing organic matter. It is humus that feeds the soil microbes and improves the texture of the soil. It makes the soil easier to work, has better aeration and absorption, and holds more water. Nutrients are held best by a soil with good sponge structure. Compost provides nutrients for plant growth, and the humic acid in compost helps release locked-up nutrients.

**Figure 3-5: Forest Composting**

Photo c/o creativecommons.org

Compost also increases the earthworm population of the soil. The "lowly" earthworm is nature's champion humus maker. The earthworm aerates the soil by its tunnels and brings up nutrients from the deeper subsoil so that the plant roots can use them. As the earthworm burrows the soil, it passes soil through its stomach. Earthworm casts (their manure) are five times richer in nitrogen, seven times richer in available phosphates, and 11 times richer in potassium than the soil it lives in!

Composting is a clever time-saving device. When manure and other raw organic matter are applied to the soil, it must be broken down and turned into humus. This takes time. Compost, with its readymade humus, gives the plants and soils exactly the right food, ready to use. In making a compost heap, the farmer "rolls up the floor of the forest" and arranges it in a pile. There, he or she can keep it at just the right moisture to cause quick decay. In applying compost, the smallholder farmer overcomes the smallness of his or her holdings by increasing the internal surface of the pore spaces of the soil. This provides the maximum possible area on which the root hairs can collect water and food materials. To maintain this maximum pore space, the soil must be well supplied with humus and a large soil population.

Anything that will decompose will provide nutrients for plant growth. So, anything that will decompose or rot can also be composted. The materials that can be used vary, from kitchen scraps to green grass to cow manure. Remember, anything that will rot will make compost.

### *The Kitchen Compost Method*

A compost pile can be made either by arranging the materials in an open pile or by placing them in what is called a compost bin. A bin is usually made like a large box with three or four sides. It keeps the compost pile together in a neat stack.

This type of compost is well-suited to the small-scale gardener, because common materials are used: kitchen scraps[4], rich garden soil, and fresh vegetation such as fresh cut weeds or grass. Fresh vegetation is much better to use than dried vegetation, because it contains more nitrogen, which makes it decay quicker.

To make a compost pile, the ground underneath the pile should be loosened or forked in order to expose the bottom of the pile to soil microbes and to provide good drainage. The materials are added to the pile in 2-inch layers. The vegetation layer is first, then a layer of soil to cover the vegetation and kitchen scraps. Have enough scraps for a 2-inch layer; scraps can be saved in a container with a tight lid, such as a zinc trash can.

Soil should be added quickly after the vegetation and kitchen scraps are placed in the compost, for two reasons. First, the soil contains microbes that will speed up decomposition. Second, the soil layer will help keep the smell down and prevent flies from laying eggs in the compost.

As each layer is added, it should be watered lightly. When watered, the pile should be evenly moist, like a damp towel. It must be completely wet, but should not give out much water when it is squeezed. Correct watering is a very important step. Too little water will slow down

4 Grease, oil, fish, meat, and dairy products should not be added to kitchen compost, nor should cat or dog manure.

the composting process. Too much water will do the same. For a compost pile to work, it depends on the proper mixture of air, soil, nutriments, microbes, and water.

To speed up the composting process, three methods can be used. The easiest method to speed up decay in a compost pile is to increase or add nitrogen. If materials contain very little nitrogen, which is the food for microbes, they decay very slowly. Materials with little nitrogen, such as sawdust, dry leaves, wood shavings, and dry grass, will take very long to decay if they are not mixed with a material that is high in nitrogen. To speed the decay of low-nitrogen materials, nitrogen-rich materials such as fresh-cut grass, poultry manure, vegetable wastes, or fertilizers such as 5–10–10 can be added to the compost pile. Three to 5 pounds of fertilizer per cubic yard of compost should be enough to speed up decay in a slow compost pile. To decompose carbon, the microbes must have nitrogen.

The size of the compost pile should be no smaller than 3 cubic feet. Smaller piles allow too much air in, and do not build up the necessary heat for proper composting.

Another method to speed decay is to increase the surface area of the materials in the compost pile. The smaller the materials, the greater the exposed surface area on the materials. Thus, microbes have more area to live on. Broken-up twigs will decompose more quickly than twigs that are left whole. Chopped grass will also decay faster than unchopped grass. The compost pile should be located near the garden and a water supply, so the finished compost can be easily carried to the field and unfinished piles can be kept at the right level of moisture.

Compost made according to the kitchen composting method should be ready in two to three months, with no turning needed. Compost is ready when it is dark and "crumply" looking, and you cannot tell what materials were used in the compost heap. The compost should smell good!

A pile 3 feet by 3 feet by 3 feet will yield 1,000 pounds of compost. The minimum amount of compost to be applied is roughly 1 to 3 inches thick on the soil surface. This would typically be a layer 1 to 3 inches thick. A pile 3 feet by 3 feet by 3 feet should supply three 100-square-foot beds, with some compost left over.

There are many methods of composting. We have chosen two more methods to give a wider viewpoint on how to compost. The farmer should experiment with the different methods and the materials most available to him or her to produce the best-suited compost for the area and resources.

### *Indore Composting Method*

The Indore compost pile is built 5 to 10 feet wide, 5 feet high, and any length. Wooden stakes 3 or 4 inches in diameter and 6 feet tall are set 2 feet apart along the center of the pile. These allow air into the pile.

The materials that can be used in this method are plant, animal, and garden wastes, kitchen waste, dustpan waste, wood ashes, weed cleanings from roadside ditches, sawdust, and any other kind of organic materials that can be found in large enough quantities.

The first layer is of straw or brush, about 12 inches thick. This provides a base for the pile. Then the heap is built in layers: first, a 6-inch layer of green matter such as weeds, crop wastes, and kitchen waste, then a layer of animal manure (less if poultry manure is used), followed by a thin layer of soil.

These layers are repeated until the pile is 5 feet high. Each layer is watered to resemble a squeezed-out sponge. A pile is turned after six weeks, and again after 12 weeks to allow air to penetrate all parts of the pile. The compost should be ready to use in three months.

### *14-day Composting Method*

This is called the fast method of composting. The main difference in this method is that all materials used in the compost pile are shredded in a gas-powered shredder-grinder. Shredding and chopping the materials increases the speed of decomposition, increases aeration, improves moisture control, and makes the pile much easier to turn.

Large-scale community compost piles can be turned by tractors equipped with front-end loaders.

There is no layering in this method. All the materials are shredded and mixed together and piled into piles 5 feet high. In three days the first turning is made, and then the pile is turned every two or three days. After 12 to 14 days, the heat of the pile has stopped and the compost should be ready for use. Moisture is very important to obtain finished compost in 14 days, and should be carefully attended.

In some dry areas the farmer may have to make the compost in a pit, to protect it from the sun and wind. Covering a finished compost pile with a thick grass mulch or hay mulch will also conserve moisture and protect the pile from the drying sun and wind.

A well-made compost heap should begin to heat up in two or three days. This can be checked by sticking a metal rod into the center of the pile then feeling the rod for warmth. The temperature should reach about 160 degrees Fahrenheit (71 degrees Celsius) and stay at this point for about three weeks. The high temperature ensures proper conditions for the growth of microbes while destroying weed seeds and diseases.

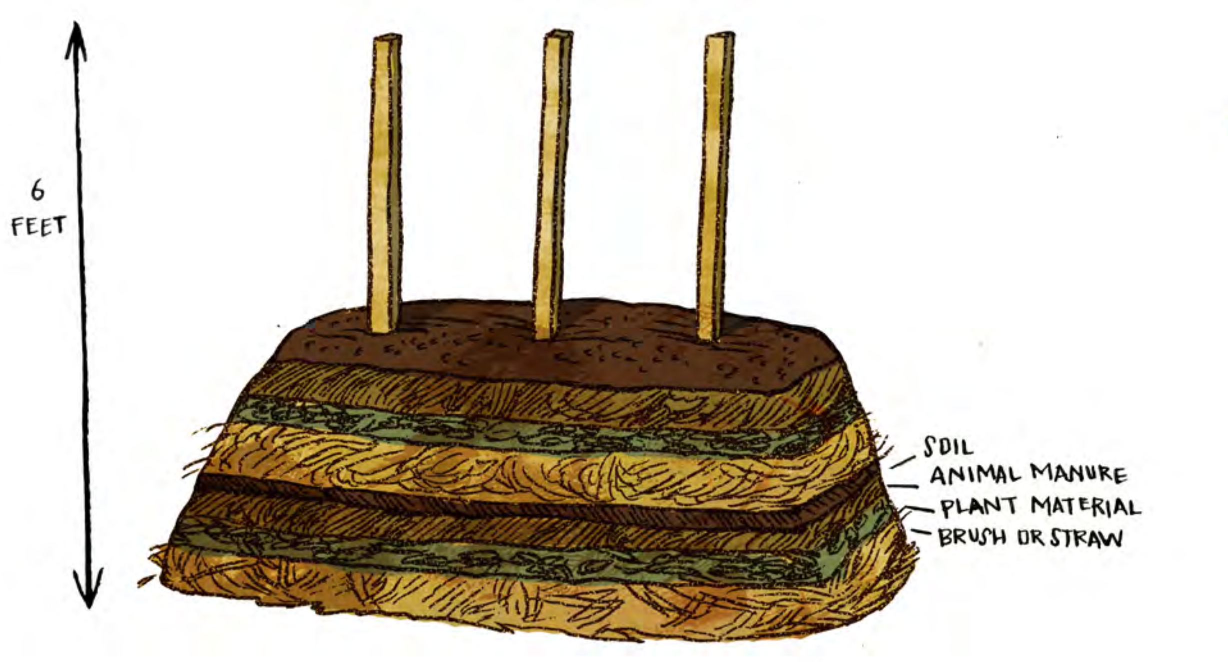
If the pile does not sink in the first few weeks, or if it smells of ammonia, it is a sign that the heap has poor aeration, is packed too tightly, or is too wet. In this case, the best thing to do is to start over.

A well-made compost pile creates an environment in which decay-causing bacteria can live and reproduce at the highest level of activity. Fresh manure, garbage, and other organic material change into humus-rich compost as a result of the activity of microbes. It is up to the farmer to learn how to best provide and maintain these conditions using the locally available resources.

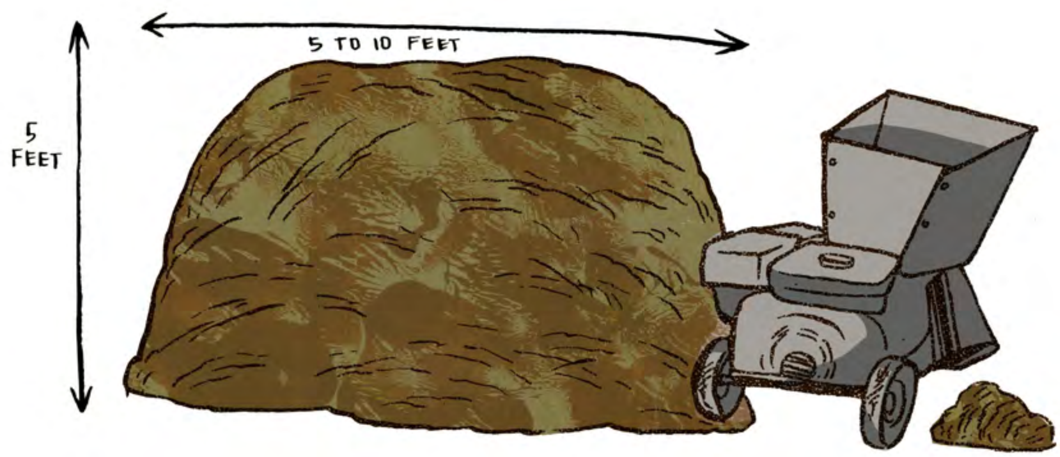
Some organic materials should not be used in the compost pile. Diseased or insect-infested plants, for example, should be burned first, and their ashes used as compost material. Hard-to-kill weeds should not be put in the compost pile, nor should materials that take too long to decay, such as tree branches.

**Figure 3-6: Three Methods of Composting**

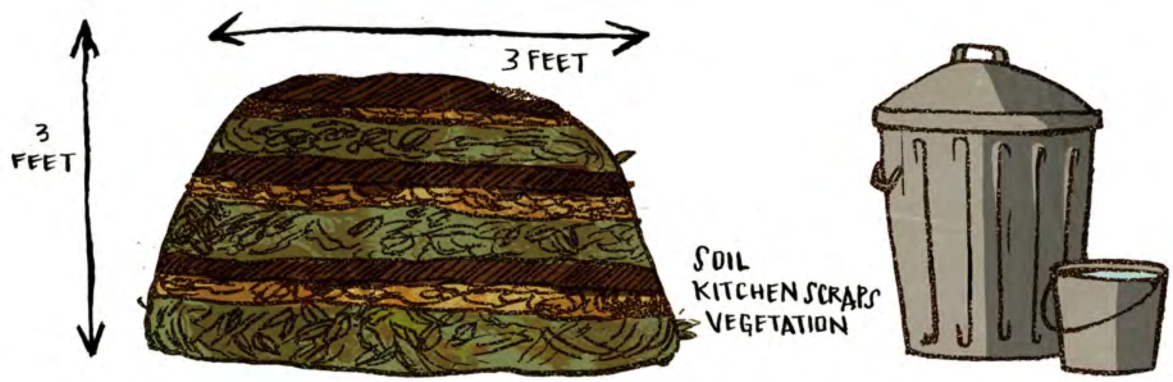
**Indore Composting Method**



**14-Day Compost**




**Kitchen Compost**




## Soil Management Program

For the farmer to intensify and increase the farm or garden's productivity, he or she must learn to maintain and conserve the soil's fertility. To do this, he or she must design and follow a soil management program suited to the soil needs and based on locally available soil-building and fertilizing resources.

An effective soil management program must meet four basic requirements:

1. Conserve and maintain the fertility of the soil.
2. Supply plant nutrients in a balanced form for healthy productive crop growth.
3. Supply amendments to build and maintain the sponge structure of the soil.
4. Return and maintain the soil organic matter and microbe population.

# Ch 3: Soil Management and Improvement

When designing a soil management program, the farmer should first have the soil tested to determine the pH and the major nutrient levels. This will give the farmer the information he or she needs to decide whether to adjust the sourness of the soil. It will also give the farmer an idea of the general fertility of the soil.

The farmer should then locate and list all locally available soil-building, fertilizing, and composting resources, such as manures, bagasse, and filter press. The farmer should make careful note of which materials are easy to obtain near the farm, especially those that can be obtained free of cost or very cheaply.

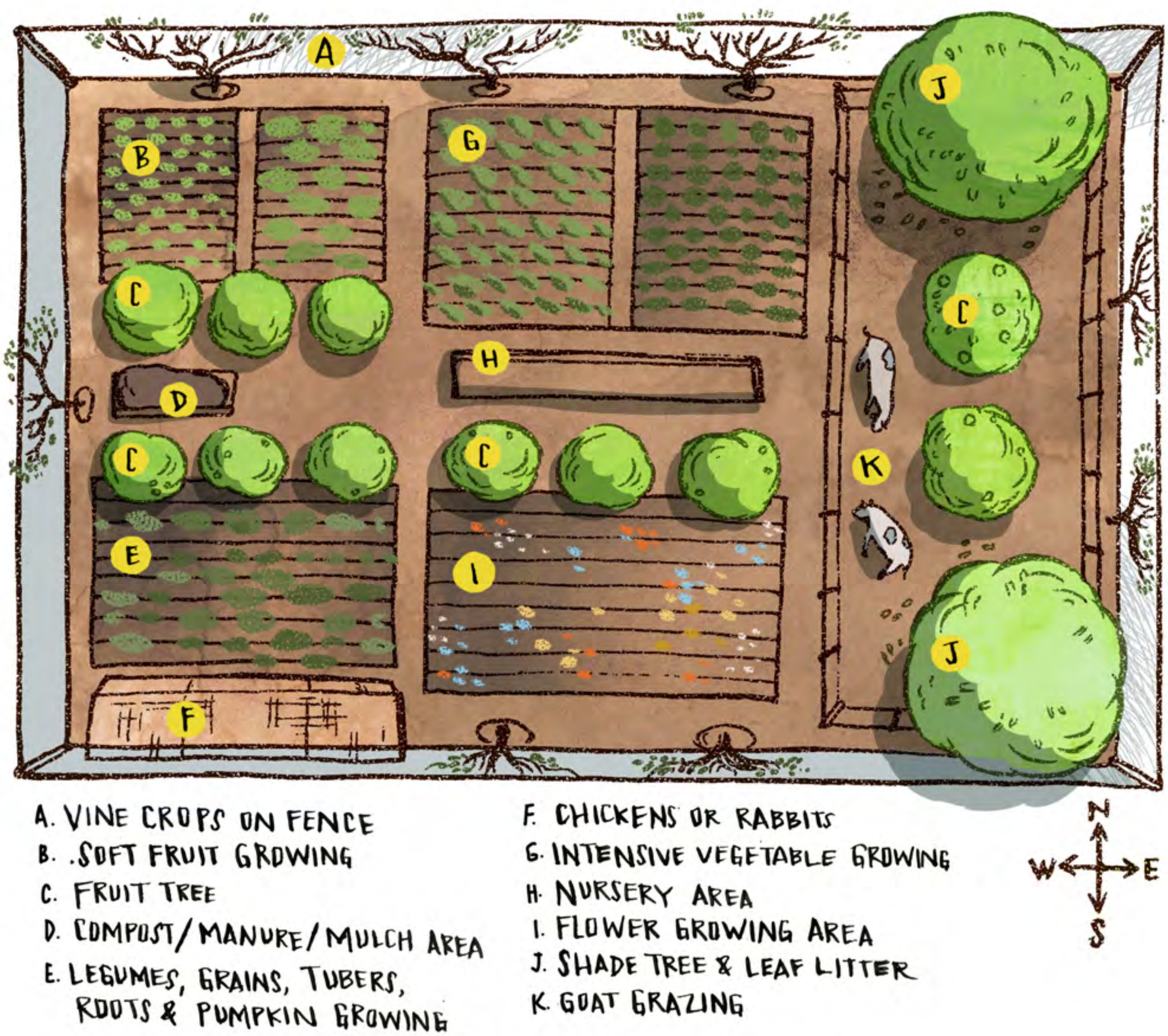
Using the information from the previous sections of this manual, the farmer should figure how much manures, organic fertilizers, and inorganic fertilizers he or she will need. Now, the farmer should have enough information to estimate the cost of the fertilizers and manures he or she needs to begin the soil management program.

For the smallholder farmer, it may be difficult to find or afford the amounts of materials recommended for intensive market gardening. Composting will greatly help this problem. By building compost piles, the farmer can produce valuable soil-building material from common waste materials, kitchen scraps, bagasse, and other materials. The farmer will also find it helpful to always have a plot of the land planted to a green manure crop, such as cow peas and wing beans. This adds nitrogen and organic matter to the soil and provides a good supply of compost material for cutting.

The basis to good soil management is the return of decayed organic matter to the soil. Good management of the farm's animal manures will conserve their value and return much fertility to the soil.

To properly manage the soil, the farmer must develop all of the soil-building resources. All organic wastes should be returned to the soil through a soil management program that imitates nature's life cycle to build soil fertility. This natural soil fertility program not only increases present productivity, but also ensures that soil capabilities will be preserved for future productivity. This is especially important as demand for food increases and as a nation strives to become self-reliant in food production. The skilled farmer, through proper soil management, makes important contributions to present and future generations.

**Figure 4-1: Garden Thinking**




## Garden Location

Many factors must be considered in planning a garden. First of all, garden location is very important. The garden site should be near the home so it can be easily protected and cultivated. The soil should be well-drained, deep, and rich. If the area is subject to heavy winds, locating the garden in a protected area is helpful; for example, behind a tree line or with fast-growing shrubs or other plants planted to serve as a windbreak.

The garden should not be near any large trees that would shade the crops or whose roots would rob nutrients and moisture from the crops.

# Ch 4: Garden Planning

The farmer should become a keen observer of the climate and seasonal changes in the area. Temperature, rainfall, and wind all affect the types of crops and the planting times. For instance, certain crops prefer cool weather. The skilled farmer/gardener will know when the coolest season of the year occurs, and plant cool-season crops (such as cabbage, lettuce, and red peas) so they can take advantage of the cool temperatures.

The farmer should also take note of all local resources for building, mulching, and composting. A well-tended bamboo grove will provide the gardener with much material for building fences, huts, and trellises for vine crops. It also provides leaves for mulch and compost.

## Garden Plan

The next step to planning the garden is actually drawing up the plan. Having a plan to follow will save the farmer/gardener much time and worry. By properly planning the garden or farm, the farmer/gardener can expect maximum production and minimum maintenance

**Figure 4-2: Planning**


The best way to draw a plan is to use large sheets of paper and draw out rough lines of the farm or garden. Permanent parts (such as huts, pathways, trees, and composting areas) should be drawn first. North and south should also be marked on the plan. Then the placement of each crop, in order of importance, should be drawn, considering the time and space that can be devoted to each.

When considering which crops to grow, the farmer/gardener should note the market value and demand for certain cash crops and their adaptability to the land and climate. The nutritional value of crops should also be considered. By growing a major portion of the family's food, as well as a cash crop, a farmer can save much money and, at the same time, provide more and better nutritious food for the family. The farmer should seek the local agriculture officer's advice when choosing varieties of crops best adapted to the area.

## Planning to Plant

With the help of the first two tables in Appendix A, the farmer should be able to determine how much seed will be needed. Table A-1 gives the number of seeds per ounce for each vegetable crop, with the germination rate for each crop. Specific seed amounts and germination time frames will vary, depending on the environmental conditions at post.

Program officers, extension agents, master farmers, and ministry officials can provide more specific information.

Table A-2 gives spacing for intensive planting, and Table 3 gives the number of planting centers per 100 square feet of intensive bed. If the farmer wants to plant 200 square feet of the intensive bed in bush beans, he or she can look on the spacing chart and see that bush beans are planted on 4-inch centers. From the same chart, the farmer can see that there are 900 4-inch centers per 100 square feet. That would be 1,800 planting centers for 200 square feet. On the seed per ounce chart, the farmer can see that bush beans are planted two seeds to the center. That would mean he or she needs 3,600 seeds (2 seeds per center for 1,800 planting centers). The chart also tells the farmer that there are 100 bush bean seeds to the ounce. So the farmer would need 36 ounces (2.25 pounds) of bush bean seed.

By mastering the use of these charts, the farmer will also be able to estimate yields. For example, from the charts the farmer can determine that there are 56 cabbage plants per 100-square-foot bed if they are planted on 15-inch centers. If each cabbage produces a 1-pound head, the yield would be 56 pounds per 100-square-foot bed.

## Succession Planting

By careful planning, the farmer/gardener can know when one crop will be finished and the next crop can be planted in its place. This is called succession planting, which can greatly increase the productivity of the garden. This manual includes three succession-planting charts. By knowing the time it takes for a crop to mature, the farmer can plan a crop to follow. This will keep the garden producing year-round.

## Companion Planting

When planning the garden, remember the companion planting chart in Appendix A (Table 4). Plan the planting scheme so that plants that help each other grow and resist insects will be near one another. Keeping a garden plan will help the farmer/gardener remember the crop rotation cycles.

## Garden Notebook

It is best if the farmer/gardener can keep a garden notebook. In this notebook, he or she should note crops and varieties which did best and which did poorly. He or she should also note the dates when certain insects appeared, the dates of planting and reaping, and all other relevant information and observations. This notebook will help the farmer improve the garden and crops every year. It will, for example, help him or her be prepared to fight insects and note areas of soil that need special attention.

## Production, Costs, and Income

Small-scale market gardening can be a profitable business if it is approached by the farmer/gardener as a long-term profession rather than a way to make a little money. Planning ahead pays dividends.

The most important thing professional market gardeners must do is produce good-quality fruits and vegetables. If the small-scale grower cannot maintain quality, retail customers and buyers will not take the time and trouble to deal with him or her regularly. If the grower is truly professional and aware, he or she will be able to find and use free resources such as manure, grass for mulch, bat manure, and any other organic materials that can help build the soil fertility for better yields and quality.

When planning the market garden, the farmer should keep an account of all the expenses and income, so he or she will be able to better manage the business. Selecting crops best suited to small-scale market growing depends on the soil, the climate, and the farmer's skill.

Properly prepared beds are an important part of intensive vegetable production. For the most intensive vegetable production, the beds should be raised with the soil prepared to a depth of 2 feet to permit healthy root development. If beds are not prepared, fertilized, and maintained with proper care, the close intensive planting methods recommended in this manual will not maximize plant growth and crop yields. With properly prepared beds, the plant is provided with the best of growing conditions. Root growth and plant health are improved. Proper preparation of vegetable beds is based on natural fertility cycles, which build the soil while producing crops.

## Intensive Raised Beds

A raised bed is a planting area that has been forked and worked so the planting surface is 4 to 10 inches higher than the original ground level. Raised beds are usually made 3 to 5 feet wide, and any length that the gardener wishes.

The width of a raised bed has a great number of advantages over wider beds. Garden jobs such as weeding, planting, fertilizing, harvesting, and insect control can be performed from each side of the bed without having to walk on the bed. This is important because vegetables are short-lived plants, so their root growth and health is very important. Walking near vegetable plants compacts the soil around them, making root growth more difficult and even injuring the roots that have grown. Root hairs take in nutriments, water, and air for the plants. Plants lose their root hairs when they have to push through tightly packed soil.

When planning an intensive farm and garden, all planting space must be used to maximum advantage. Pathways and roads should be carefully located to be convenient while taking up as little arable and productive land as possible. Permanent raised beds enable maximum use of a planting area. With permanent raised beds, all fertilizers and soil conditioners are placed directly in the root areas, never in paths. Beds are usually raised 4 to 10 inches higher than the walkways, so the areas where plants are grown are distinct from other work areas.

Preparing the raised bed is the most important step in intensive vegetable cultivation. The prepared bed should have loose soil with good texture and nutrients. This allows steady penetration of the roots for growth and thus uninterrupted growth of the plants.

In the intensive method of vegetable cultivation, crops are grown so closely together that when the plants are almost mature, their leaves are touching. In other words, when an intensively planted bed of cabbage is almost mature, there is almost no visible ground in the raised bed. You would see a solidly covered bed of cabbage plants.

This method of planting not only allows more plants to be grown, but also permits the closely spaced plants to develop what is called a "mini-climate." That means that the plants are grown so closely together that they shade the soil surface, like living mulch. This keeps the most important area in the soil, the topsoil, cooler and moister. The shade also keeps down weeds when the plants are large enough. It keeps the soil surface from forming a hard crust and conserves moisture and water for the plants. With the increased number of plants in a bed, however, it is very important to prepare, fertilize, and maintain the beds properly.

To make room for the roots of this large number of plants, intensive vegetable cultivation requires deep soil preparation. With deep preparation of the soil, roots will grow down instead of spreading out and robbing the nutrients from neighboring plants. The deep growth of the root systems also reduces the need for watering, because the deeper soil holds water longer. Deep penetration of the roots also reduces the need for heavy fertilization during the growing season, as the deep roots bring up nutrients from the subsoil. This utilizes those nutrients that travel downward through the soil and are normally lost to shallow-rooted plants.

The raised-bed method can be adapted to power hand tractors. Larger four-wheeled tractors can also be used, but hand tractors or hand cultivation is most suitable for soil preparation, maintenance, and care in the intensive raised beds.

## Making a Raised Bed

Making a raised bed for vegetable production is not difficult, but it is time-consuming. However, it is important that the bed be prepared properly; the effort will pay off in the health of plants and the productivity of the garden. Following are steps to be followed to prepare a raised bed.

### *Step 1: Loosening and Cleaning the Soil*

When initially preparing the soil, the first operation is to loosen the soil to a depth of 12 inches with a spading fork. This operation should not turn over the soil. The soil is simply loosened and weeds are removed. At this point, any soil amendments that are needed should be added and mixed well into the soil. For example, add 1 to 3 cubic yards of compost or aged manure to every 100 square feet of soil if the soil has high clay or sand content. If the

**Figure 5-1: Intensive Raised Bed**

Photo c/o creativecommons.org

soil texture is good, less texturizer is needed. The gardener should develop good judgment on the needs of soil through experience.

### *Step 2: Double-digging the Soil*

The next operation is to "double-dig" the raised bed. Double-digging is a soil-preparation method of deep plowing. The goal of this method is to loosen and improve the soil to a depth of approximately 2 feet (24 inches). On the first preparation of a raised bed, the gardener may be able to reach a depth of only 10 to 14 inches with reasonable effort. Gradually, after several croppings and with improved soil fertility and structure, the depth will increase to the desired level. Each time the bed is worked, the depth can be increased from 1 to 3 inches. Beds prepared by this method become easier to work as the soil texture improves. The growing depth should be increased in this way by 3 to 6 inches per year in shallow beds. The best tool to use when double digging is a D-handled flat spade.

As discussed, it is important to build soil fertility and structure to promote healthy plant growth. Before double-digging, first spread a thick layer of compost over the entire bed: 8 to 24 cubic feet of compost per 100 square feet of raised bed.

The steps involved in double-digging the bed are shown in the following two images. Carefully study these steps, which are the most important aspects of intensive vegetable cultivation.

**Figure 5-2: Double-digging a Bed**

Photo c/o creativecommons.org

**Figure 5-3: Spreading Fertilizers and Amendments on a Bed**

Photo c/o creativecommons.org

1. To double-dig a trench 1 foot deep and 1 foot wide (1 foot by 1 foot), dig across the width of one end of the bed. Move the soil from this first trench to the opposite end of the bed. This soil will be used later to fill the trench that will be made at that end of the bed when the double-digging is finished.

2. Next, spade the trench that has been made to loosen the soil at the bottom of the trench. Push the spade into the soil at the bottom of the trench as far as possible. The goal is to loosen the soil at the depth of another 12 inches, but one should go only as deep as is possible with reasonable effort. Leave the spade in the soil as deep as it has penetrated. Move the spade forward and backward with a rocking motion until the subsoil is reasonably loosened. Then return the spade to the upright position and remove it. Move several inches down the trench and repeat the process until the entire trench bottom has been worked in this manner.

3. After finishing the first trench, go immediately beside the trench and dig another one across the width of the bed. Form the second trench beside the first trench by throwing each spadeful of soil from the second trench into the first trench. You may have to go over each trench as it is made to get the proper size. This task involves moving the top 12 inches over into the previously made trench.

4. After the second trench has been made by filling the first trench with the soil, loosen the subsoil in the second trench. Do this in the same manner used for the first trench.

5. Then, make a third trench in the same way, a fourth trench, and so on, until the entire bed has been double-dug. At the end of the bed, spade the soil that was carried from the first trench into the last trench.

### *Step 3: Rest and Fertilization*

After the bed has been double-dug, it is usually allowed a day's rest to settle. After a day, the garden should be fertilized with bat manure, filter press mud, wood ashes, chicken manure, or other organic fertilizers. Superior yields and quality can be achieved if natural fertilizers are used in the correct amounts and in combinations along with bagged ones. Program officers, extension agents, master farmers, and ministry officials can provide information regarding application rates of organic and inorganic fertilizers.

For example, to fertilize a 100 square foot bed, you would need a combination of 2 to 4 pounds of bat manure or filter press mud to supply the phosphorous, 2 to 4 pounds of wood ash to supply potassium, and 5 to 10 pounds of chicken or 25 to 50 pounds of aged cow manure to supply nitrogen. When bat manure is used as a phosphorous source, it supplies some nitrogen, so less chicken or animal manure should be used. The fertilizers should be broadcast on the surface of the bed after leveling it off and shaping it. They must then be sifted in 2 to 3 inches deep with a spading fork to avoid losing their value. The bed must then be re-leveled and reshaped.

### *Step 4: Forming the "Lip" of the Bed*

If the soil is heavy clay, it is best to form a lip on the outer edges of the beds, to help control erosion. The lip can be easily made with the use of a heavy-duty garden rake or spade. Once the texture of the soil is improved, erosion will not be a problem. Erosion is minimized when soil has good structure, which allow for higher infiltration and percolation rates. The bed should be 4 to 10 inches higher than the original surface of the soil and protected by the lip of the bed when it is finished. A steeper angle will only encourage erosion.

**Figure 5-4: Forming the "Lip" of the Bed**

This is the final step in preparing the raised bed for vegetable cultivation. These steps should be followed carefully in forming and maintaining vegetable beds so that the productivity of the beds is promoted at the highest possible levels.

## *Bed Preparation Time Requirements*

The initial preparation of a raised bed with moderately heavy soil, including the seeding and transplanting for the bed, will require 6 to 12 hours for 100 square feet of bed that is 5 feet by 20 feet. After the first preparation, only 4 to 6 hours should be required to re-prepare and re-plant the beds. As beds become older, they will be more loose and fertile. Less work and time will be required for preparation.

After the beds have been planted, about 15 to 30 minutes per day are then required to maintain a 500-square-foot area. This area is large enough to provide one person with vegetables for 12 months of the year in a climate that has a 9-month growing season.

**Table 5-1: Instruction Chart for the First Preparation of a 100-square-foot Bed with a Heavy Clay Soil (approximate times for a case in Jamaica)**

| First Preparation, 100-square-foot Bed, Heavy Clay Soil |
|---|
| 2 hours: Soak (for hard, dry clays) |
| 2 days: Partial drying out |
| 1–2 hours: 12-inch loosening and weeding of soil with spading fork |
| 1-day: Rest period for the soil |
| 1–2 hours: Add 1–3 cubic yards of compost (preferably) or aged manure (2-year-old cow or 2-month-old horse) to soil with poor (very clay or very sandy) texture. Less if the soil is better and dig in well. Any pH modifiers can be added at this time |
| 1-day: Rest period for heavy soil |
| 2–4 hours: "Double-dig" soil with flat spade after adding 8–24 cubic feet of compost to the top of the bed<br><br>2–4 hours: Add 2–4 pounds bat manure or filler press, 2–4 pounds wood ash, and 2–4 cubic feet aged manure or 5–10 pounds of chicken manure or 1–2 pounds of complete inorganic fertilizer to surface of bed after leveling off and shaping the bed. Sift in fertilizers 2–3 inches deep with spading fork.<br><br>1–2 hours: Re-level and shape bed<br><br>1–2 hours: Plant or transplant |

## Production on Raised Beds

The intensive methods of vegetable production are best adapted to areas with adequate rainfall or where some irrigation or water control is available. When there is adequate water available, the raised beds will produce twice as many vegetables as row crop production with the same amounts of water.

The methods conserve water. However, it is crucial for the farmer to have control over the water to ensure a sufficient amount. The plants must have sufficient water constantly until they have grown enough leaves to supply shade for their roots and the soil underneath them.

Research indicates that proper application of the methods will result in four times as many vegetables per acre than the amount produced by farmers using mechanized and conventional agricultural methods. The evidence also indicates that the method uses one-half as much water per pound of vegetables grown as that consumed by commercial agriculture.

When using the intensive raised-bed methods, maximum yields may not be reached in the first season. Yields will depend upon the natural fertility and structure of the soil and the farmer's ability to obtain natural and inorganic fertilizers to return organic matter and humus to the soil.

Maintaining and increasing production is dependent on the fertility and humus content of the soil. This must not be neglected!

## Mechanization and Land Preparation for the Small Farmer

This section discusses the use of hand power tractors to prepare land. These devices are not the only mechanized or animal-driven methods of land preparation. There are small tractors, animal-powered machines, and other tools that can be used to prepare land or for other processes in crop production. There are advantages and disadvantages of each mechanized tool or animal-powered machine, which should be considered when deciding which is the best for each situation.

Where tractors are available, they can be of great assistance to the smallholder farmer in reducing his or her workload and saving time. Heavy soils may require plowing and cross-plowing a few times to be well broken. In addition, harrowing is usually done last to refine the soil after plowing. Sometimes a tractor with a rotavator attachment is available. The rotavator is made to plow and harrow the land in one operation.

There are tractor attachments for preparing beds and furrows for planting operations. This equipment can help the farmer greatly, leaving only planting and cultivation for hand labor.

# Ch. 5: Soil Preparation for Intensive Gardening

The most obvious disadvantage of large equipment is that it cannot be used on hillsides. In addition, the use of large machinery does not allow intensive cultivation of land. However, some forms of power machinery are well-suited to intensive cultivation and sloping lands. A power hand tractor is one of these.

## *Power Hand Tractors*

A power hand tractor, also known as a rototiller, is a two-wheel tractor powered by a small gas engine, usually 6 to 10 horsepower. These tractors are typically equipped with a rotavator attachment. Hand tractors are guided by two handlebars, similar to bicycle handlebars, which are controlled by the farmer. On heavy soils, these types of machines will be much slower than full-size tractors, but they are very effective and will save the farmer much time and labor. An advantage of small tractors is that once the farmer is familiar with this type of machine, he or she can do most maintenance and repairs right on the farm.

Power hand tractors can also be used to turn cover crops, green manures, and soil conditioners into the soil. Standing crop residue can be turned and chopped effectively into the soil with these machines.

**Figure 5-5: Hand Tractor Designs**

Photo c/o creativecommons.org

*Power Hand Tractors in Raised-bed Preparation*

Power hand tractors are well-suited to preparing raised beds and for deep mixing of the soil texturizers and fertilizers used in intensive vegetable production. On heavy soils, the beds should be forked and weeded by hand, and then soil texturizers such as compost and animal manure should be spread on the top of the bed. The hand tractor is run over the bed slowly two or three times, allowing deep penetration of the manures. Afterward, fertilizers such as 5–10–10 or chicken manure can be applied to the top of the bed. The hand tractor is run over the bed again, this time allowing only 2 to 3 inches of penetration into the bed so the fertilizer is not placed too deep.

After the initial hand forking of the bed, another forking should not be required when preparing the bed for a next crop. A hand tractor should be able to do these jobs completely. The farmer should then be able to turn large quantities of manure and compost into the beds to maximize the bed's fertility and productivity.

### *Hand Tractors in Row Crop Production*

Power hand tractors are very efficient when used with a row crop production scheme. The greatest role of the hand tractor in crops that are planted in rows is for cultivation. Rows of crops can be spaced to permit the hand tractor to be used to cultivate between the crops for the entire length of the rows. This greatly reduces the time and labor required for clean cultivation of row crops. Hand tractors can also be fitted with a furrowing attachment for placement of fertilizers, seeds, or plants.

**Figure 5-6: Hand Tractors in Use**

Photo c/o creativecommons.org

The hand tractor is very useful for turning under crop residue, especially in row crops where one row can be worked at a time. Legumes, green manure crops, and other residue can be easily chopped into the earth at the peak of their vegetative growth, so they decompose quickly into the fertility cycle of the soil. Proper use of this type of power hand tractor can increase and build soil fertility and soil structure.

In fairly level areas, hand tractors can be used to pull small loads of up to 300 pounds. The loads are pulled on two-wheeled carts (bicycle or motorcycle wheels) behind the tractor.

Some manufacturers of hand tractors provide several useful attachments, including electric generators, irrigation pumps, and 40-inch sickle bar mowers. The electric generator demonstrates the utility of a small machine, by enabling the use of other power tools in the fields. The sickle bar mower allows steeper slopes to be mowed and utilized for hay or mulch production. The mobility of these machines allows hard-to-get-at plots to be reached and worked effectively.

Machines and implements of this type provide the smallholder farmer with a means of farm power suited to the farm size and income. The use and care of small machinery is definitely a skill that should be developed by all professional small farmers.

## Other Types of Land Preparation

Although intensive raised beds make the most productive use of the land, other types of land preparation may sometimes be more practical. For example, large plantings (more than 1 acre) of field crops such as corn, pumpkin, or sweet potatoes are more suited to row crop production. Other factors that influence the type of land preparation are water, type of irrigation, rainfall patterns, and drainage characteristics of the soil.

### *Raised Ridges*

**Figure 5-7: Planting on Ridges**

Photo c/o creativecommons.org

The method of planting on raised ridges is best used when poor soil drainage is a problem, where flood-type irrigation is used, or where heavy rains occur.

Ridges are usually made 8 to 12 inches high, depending on the drainage of the soil. They are 30 to 36 inches wide, depending on the crop to be grown. For example, a narrow ridge is used for single-row crops like corn, and wider ridges are used for double- or triple-row crops like lettuce or cabbage. The ridges can be easily made by tractors with simple ridging plows. Many power hand tractors also have ridging plows that can do the job on most soils, except for very rocky soils. Ridges can also be made by hand with hoes and hand plows in moderate to light soils. Fertilizers are typically placed in a small furrow that is 3 to 5 inches deep in the ridge, then covered and re-ridged.

### *Furrows*

This method is best adapted to dry land farming areas. When planted in furrows, plants have more water available to them. There is less loss of water from the plants and soil by wind, because the ridges protect the root area from winds.

**Figure 5-8: Planting in the Furrow**

Farm tractors and power hand tractors can easily prepare land for this method. Hand tools such as hoes and rakes can also be used to prepare the soil in this way. Fertilizer is usually applied by broadcasting, but should be worked in to minimize loss of its nutrient value.

### *Level Planting*

This method is used where soils drain rapidly but have adequate rain or sprinkler irrigation.

Fertilizer can be broadcast and worked into the soil, or it can be placed in bands or rows underneath the rows where seeds or plants will be placed. After applying fertilizer, the farmer smooths and levels the area before planting.

**Figure 5-9: Planting on the Level**

## Mulching

Mulch is a layer of organic material (such as hay, cut grass, or bagasse) that is placed on the surface of the soil in order to conserve moisture in the soil, to hold down weeds, and eventually to improve the soil structure and fertility. Mulching is one of nature's methods for treating soil in the forest that can be imitated by the skillful farmer.

### *Advantages of Mulching*

Plants that are mulched are protected from harsh temperatures. The mulch covers the soil surface, thus reducing soil temperatures. A reduction in soil temperature helps to conserve soil moisture. A layer of mulch also protects the soil from erosion caused by wind and water.

Mulching helps soil fertility. Mulch materials contain minerals and plant nutrients. Rains wash some nutrients from the mulch into the soil. When the mulch rots down into the soil, the soil's structure is improved and plant nutrients are added to improve the fertility of the soil.

Mulching can save the farmer time and labor. A mulched garden will have very few weeds, especially if the mulch is applied before the weeds germinate and start growing. The mulch also keeps the soil loose, and thus reduces the need for cultivation.

Crops such as tomatoes, melons, and cucumbers are especially benefited by mulch. The mulch stops soil from coming in contact with the fruit and leaves, thus reducing fruit rot and fungus disease. Soil that is mulched will not allow mud to splash leaves of crop plants that are susceptible to leaf fungus diseases.

Low-lying soils that are usually wet should not be mulched. These soils are likely to harbor fungus diseases that thrive in humid and moist conditions.

### *How to Mulch*

Mulches can be applied at three different times: before the seed is planted, after the plants or seeds are planted, and after the plants are growing.

The mulch should be spread over the soil without being mixed into the soil. It should be applied thickly enough to prevent the growth of weeds.

Finely shredded mulch is easier to work with, especially around young seedlings or transplants. A heavy, coarse material such as hay, if not applied carefully, will break the leaves off young transplants and seedlings. Material such as bagasse, rice trash, peanut hulls, chopped grass, leaves, and cow manure makes fine mulch.

In a newly sowed seedbed, the mulch should be loose and thin over the row of seeds and more thickly compacted over the spaces between the rows of seeds.

Young seedlings should be allowed to become well-established and hardened before mulching. Mulching young seedlings is likely to cause damping-off fungus disease. This fungus causes young seedlings to rot at the soil line.

When using mulches such as sawdust or bagasse, a nitrogen deficiency may occur. This would cause the plants to be unable to take up nitrogen nutrients from the soil. This is only temporary, and can be quickly corrected by applying some nitrogen fertilizer, chicken manure, or manure tea.

### *Mulching Materials*

Commonly used mulching materials include sawdust, wood shavings, bagasse, guinea grass, bahima grass, rice straw, rice hulls, bamboo leaves, cocoa shells, peanut hulls, and banana trash. The experienced farmer can identify many others that will be available to him or her.

Mulching is a simple time- and labor-saving gardening method. It makes use of local resources and waste materials. If the common mulch materials, such as grass and sawdust, are not available, materials such as newspaper can be used very effectively.

The real beauty of mulch, besides conserving water, is the labor-saving advantage. A crop that is mulched will require much less weeding and cultivating.

Mulching presents another method that the farmer can make use of to provide better growing conditions for the crops, while reducing his or her labor.

Conservation and use of water is very important, especially for farmers in developing countries, where water is often a major limiting aspect of agricultural production and development.

To take advantage of the potential year-round growing seasons of the tropics and the resulting increased production, well-developed irrigation systems are often essential. A reliable supply of water is critical to intensive vegetable production.

When the farmer has an irrigation system, even though he or she may seem to have an unlimited amount of water, it should be used with care. Too much water, besides being wasteful, will leach down through the soil and carry nutrients out of reach of the roots of plants. Water runoff on a soil that absorbs water slowly will also wash away topsoil and nutrients. In waterlogged soil, plants may starve for oxygen and their roots may rot.

It is important for plants to have a good supply of water, especially when fruit formation begins. Young seedlings or newly planted transplants are very sensitive to dry soil. The farmer may have to irrigate before planting to make sure the seeds or transplants have enough water to germinate and grow. Generally, water should be applied when the crop makes its fastest growth, especially if the soil moisture is low at the time. If pools of water form in an irrigated area, it is a sign that water is being applied faster than it can be taken in by the soil. This is wasteful, destructive, and unnecessary. It should definitely be avoided. The farmer should take note of the weather before irrigating. A heavy rain following irrigation can drown the crops.

Better soil and fertility management will conserve rain and irrigation water. Better soil texture will increase the soil's ability to absorb and hold water. Once again, the importance of improving and maintaining the soil's sponge structure is demonstrated. This is a most important concern and the duty of all farmers.

## Water Catchment

In the developing world, water catchments are a common source for conserving water. This is the most common source because every person who has a roof has a potential water catchment system. Many houses have gutters and a tank to collect rainwater, but others still do not have such simple devices.

A small roof with gutters and several 50-gallon drums can collect a sizeable amount of water, which can then be used for the household or to irrigate small intensive vegetable beds to supply the kitchen with greens, onions, carrots, peppers, peas, and other vegetables. Efficient gutters and collection systems should be added to all houses in areas where no irrigation is available.

**Figure 6-1: Water Catchment**

Even when irrigation water is available, catchment can be used for small garden plots and ensures wise use of all water sources. Rainwater can be regularly and easily drained into garden plots as part of a well-planned gardening scheme.

## Shade, Soil Texture, and Water Conservation

To the farmer with no irrigation facilities available, the only means of conserving and stretching the water supply is by increasing the water-holding capacity of the soil. Of course, all farmers should pay attention to this critical characteristic of their soil. Soil structure and texture can be improved by adding composts, manures, and decaying organic matter to the soil to build up the sponge structure. Mulch can also be used to cover the soil.

Sun and wind deplete soil moisture. Windbreaks, such as a row of hedges or tall crops (such as corn or sunflowers) can be located and planted to reduce wind movement around the crops. In the case of a small kitchen garden, a bamboo wall or fence can be constructed to reduce wind movement in the garden.

Shade can be very helpful for seedbeds and special vegetable crops such as lettuce. Shade roofs can be built from bamboo or young saplings as the frame and coconut branches for roofing. This shade will keep the soil cooler and moister, thus protecting tender plants from the sun. In very hot climates with much sun, shade may be required for the production of most vegetables. Large shade roofs should be built in such climates, where possible.

## Trickle Irrigation

One method of irrigation that looks very promising to the smallholder farmer who must depend on rain and catchment water is trickle or drip irrigation. Drip irrigation (as well as pitcher irrigation, which is discussed below) requires a minimum amount of water and is very efficient in water use.

**Figure 6-2: Trickle Irrigation**

Photo c/o creativecommons.org

Trickle irrigation utilizes small plastic hoses with small water outlets spaced along the length of the hose. The small outlets have very small holes that allow single drops of water to come out at a time. The hose should be arranged so that an outlet is located at the base of each plant to be watered. Trickle irrigation is very efficient because all the water is utilized by the plant. No water is wasted to runoff or lost by moving down through the soil too quickly for the roots to take it in. This method requires very little water pressure to operate. In many cases, no pump is needed because the gravity feed from a tank can supply adequate pressure to operate a trickle irrigation system.

## Pitcher Irrigation

**Figure 6-3: Pitcher Irrigation**

Photo c/o creativecommons.org

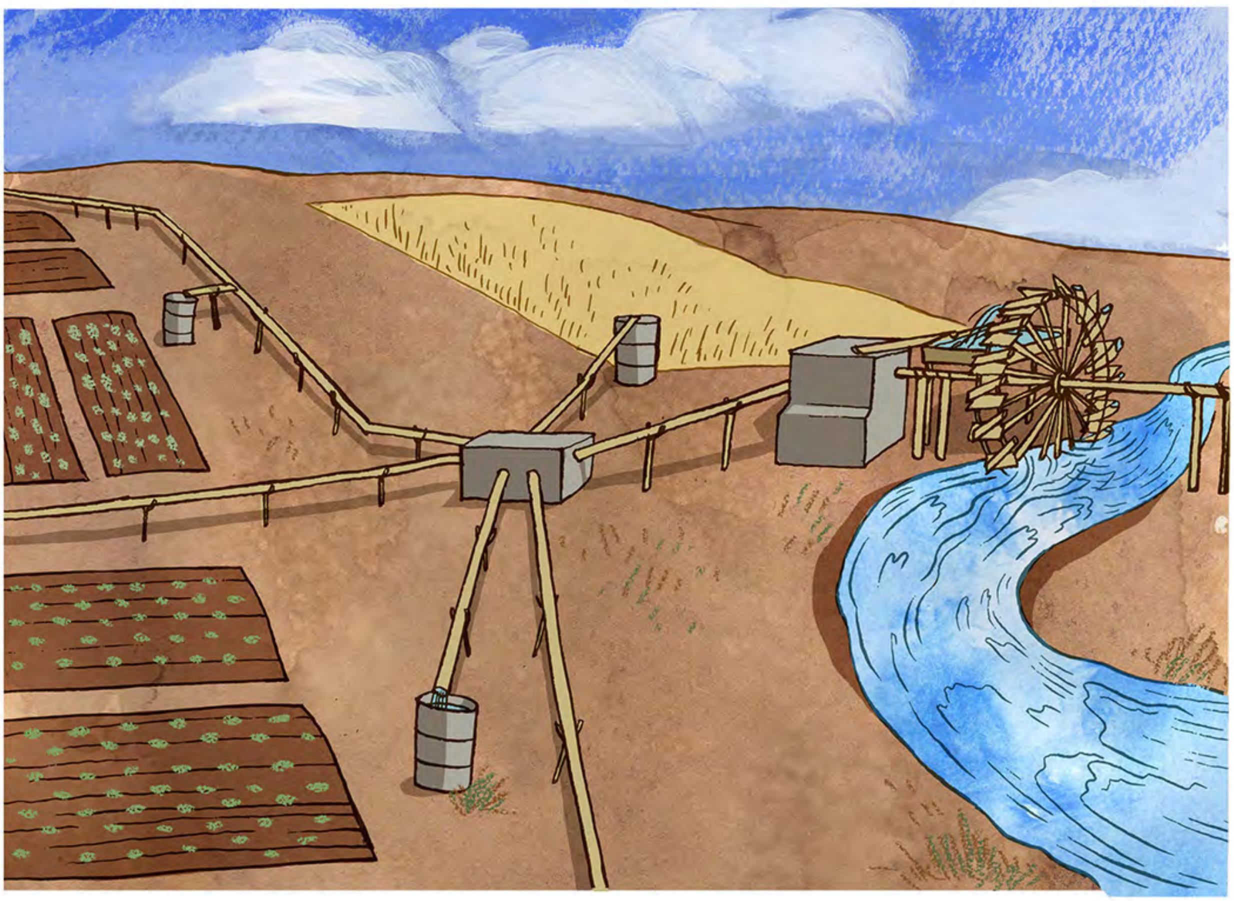
Pitcher irrigation uses unglazed baked earthen pots or pitchers buried in the soil to water the garden area. The pots are buried in the ground to the neck and then filled with clean water. Vegetable seeds are planted around each pot. Enough water soaks through the pot into the root zone to supply and maintain plant growth. Excellent results have been achieved with pumpkins and watermelons with this method.

Although this is an excellent method to use water conservatively, care of the irrigation pitchers is important. The pitchers can become breeding places for mosquitoes and other insects if they are not properly covered.

## Bamboo Irrigation

Bamboo can be used effectively in irrigation by the smallholder farmer. In areas near a river, stream, or canal, inexpensive and easily constructed bamboo lift wheels can be used with a simple bamboo piping system to bring water to crops and raised vegetable beds, as shown in the following illustrations. Bamboo irrigation is often overlooked in favor of more expensive systems with metal piping and expensive machinery and materials, but it is well-suited to the needs of the small-scale farmer or gardener.

**Figure 6-4: Bamboo Irrigation Systems**



*Water is lifted from river or canal by a bamboo lift wheel, powered by the moving water. Water lifted from the river goes into a tank, then into a feeder box, where it is distributed to different parts of the garden, to be applied from drums.*

Bamboo can be used to make effective water piping systems. The only liability is the relatively short life of bamboo when it is in direct contact with earth and water, but bamboo has many advantages.

A grove of bamboo, with little care, can come into commercial production in five years. High-quality construction material can be produced and harvested easily. Although the life of the construction material (bamboo piping is a common example) is not as long as metal or aluminum piping, the relative inexpensiveness of bamboo and the amount of production from a properly managed grove gives the farmer a reliable supply of replacement materials.

For the smallholder farmer near a stream or river, who cannot afford a power irrigation system or aluminum irrigation piping, bamboo will easily serve his or her needs. Examples of a bamboo water lift wheel are shown in the following figures.

The use of bamboo is just one method by which the skillful and clever smallholder farmer can utilize local resources to increase production and save money.

**Figure 6-5: Bamboo Lift Wheel in Action**

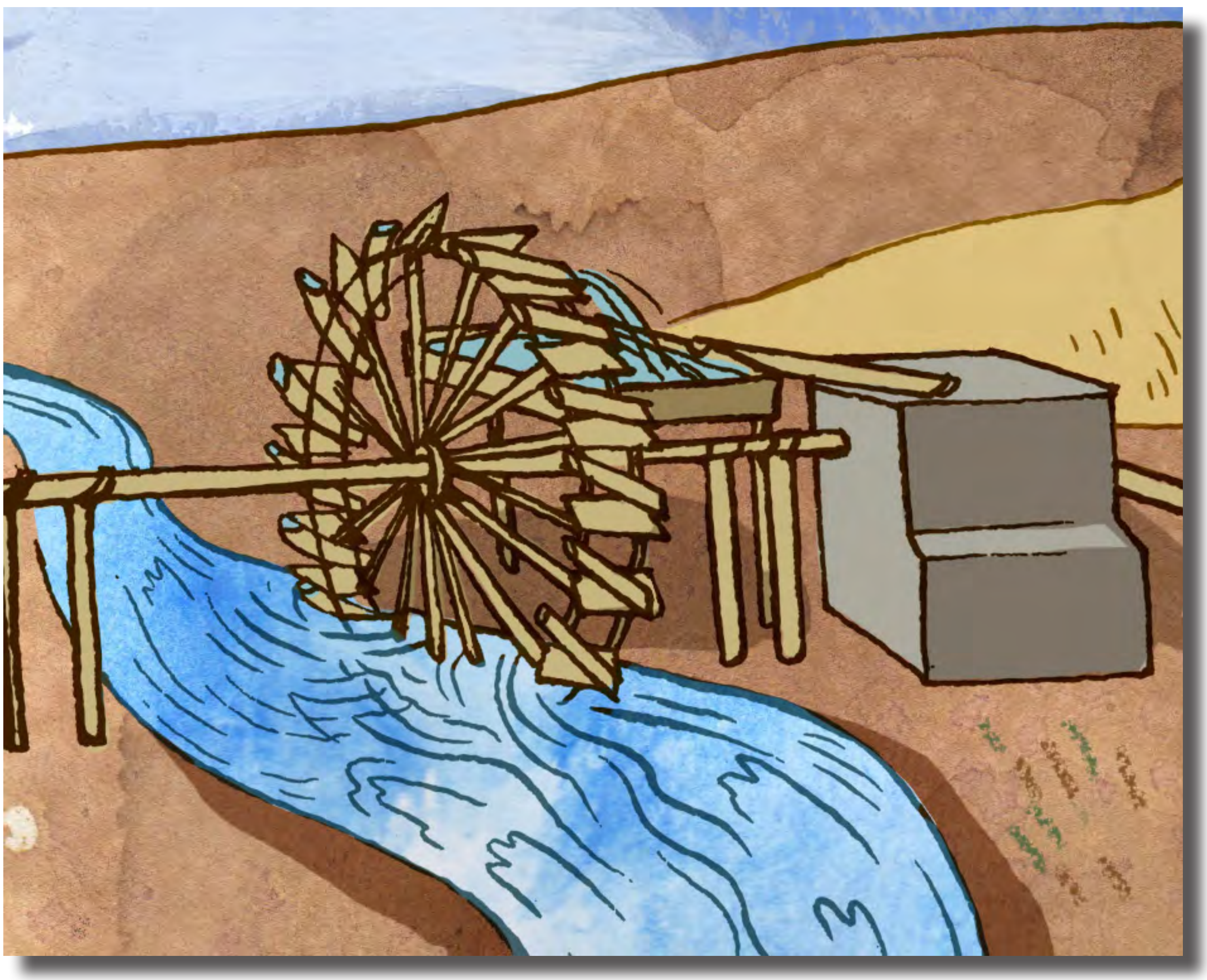


**Figure 6-6: Attachment of Cups and Paddles to a Water Wheel**

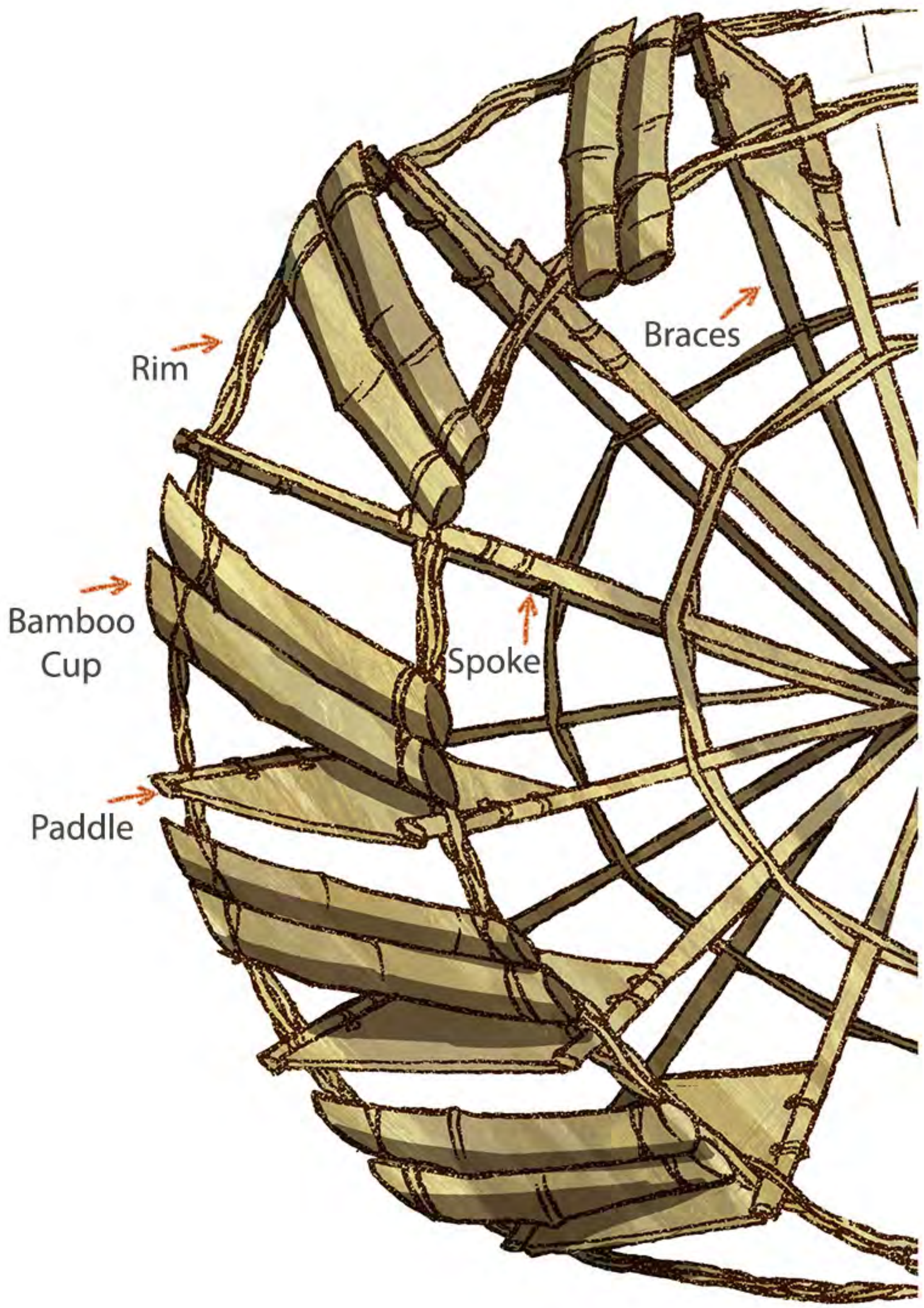


**Figure 6-7: Axle Drawing for Bamboo Lift Wheel**


**Figure 6-8: Bamboo Spokes Attached to Drum End**

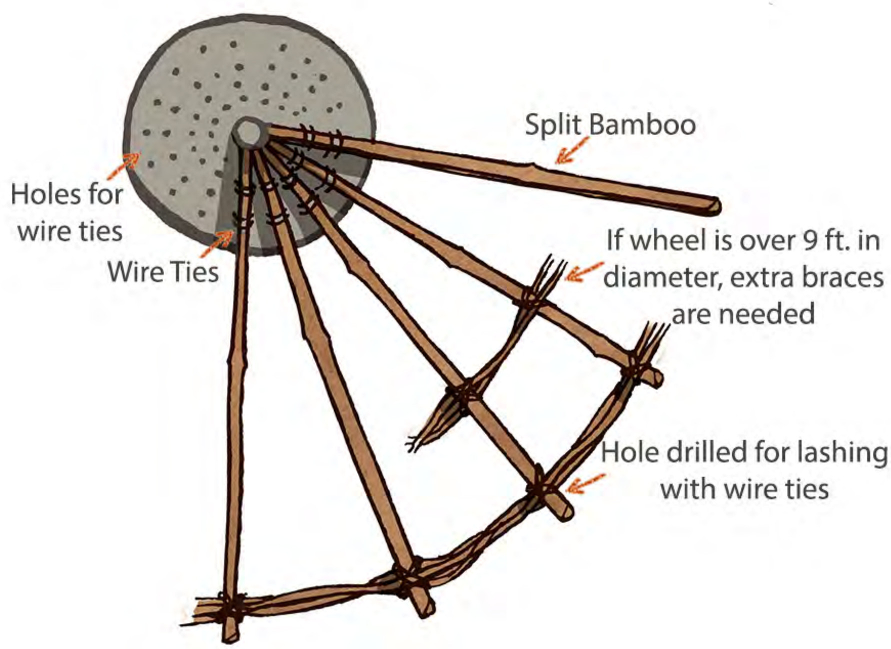



**Figure 6-9: How to Remove the Joint Membrane**

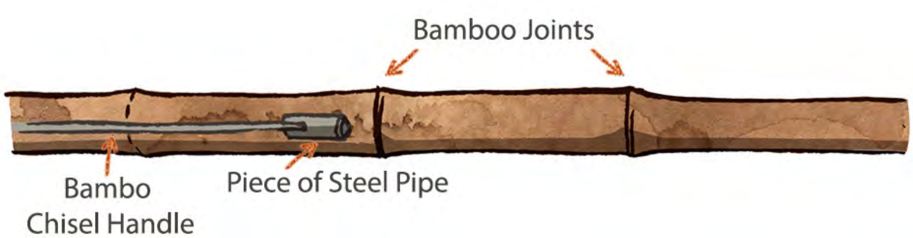



**Figure 6-10: Joining Two Pieces of Bamboo**


** The cotton from the Silk Cotton Tree may be used for cotton.*

## Controlling Water Pressure

Figure 6-11: Two Designs for Watering Cans

Photo c/o creativecommons.org

Two methods best suited to irrigate raised vegetable beds are sprinkler irrigation and watering by hand with a hose or watering can. When watering seedbeds and young seedlings, it must be remembered that these small plants are very delicate and can be damaged by a forceful water flow. A water can with a sprinkler nozzle is a helpful tool. Water cans with the sprinkler nozzle turned up are best for watering tiny plants in seedbeds, because the water coming out has less pressure when it hits the plants. It is more like natural rainfall.

Heavy irrigation or watering with forceful streams of water can damage the plants, pack down the soil, and cause erosion of the soil. Whatever the type of irrigation is used, the farmer must be alert to and aware of negative and positive effects of watering methods on the plants, the soils, and the future of the land.

## Irrigation and Watering of Intensive Gardens in Raised Beds

The large yields produced by intensive gardening methods require a constant and adequate supply of water. Deep-water penetration is required to support the large number of plants in each bed. Deep watering and soaking makes the roots go deep into the soil. Shallow watering, which soaks only the top few inches of the soil, causes the plant roots to grow shallow. Shallow roots are more likely to be damaged and affected by dry conditions. Also, the topsoil dries out more quickly than the deeper soil.

## Water Preferences of Plants

The skilled farmer, through experience, will strive to learn the water preferences of each of the crops. For example, crops such as melon, cucumbers, and tomatoes are more likely to become diseased when their leaves are wet. It is best to water these crops at the roots only, striving to keep the leaves as dry as possible. When crops are watered in such a way that the leaves are splashed with muck or soil, they are more likely to be attacked by disease.

Older, well-established plants should be watered when the hottest part of the day has passed—usually around mid-afternoon. When watering at this time of day, the cool water is warmed by the soil so that as it reaches the roots, there is less shock to the plant. Also, the plants have more time to absorb water during the night. This is important because plants do a good amount of their growing at night. If watering is done early in the morning, much water will be lost to the sun and wind through drying so less water is available to the plants. If watering is done in the evening, the plants will be more likely to be attacked by fungus and mildew caused by standing water left on the leaves in the damp nights.

As plants begin to cover the raised bed of an intensive garden with their leaves, the "living mulch" conserves the water and moisture so less watering is necessary. Until the plants begin to shade a good portion of the bed, strict attention should be given to make certain the bed is well supplied with water. Seeds, seedlings, and young transplants may need to be watered two or three times a day.

## Adequate Watering

When watering by hand, a good method for determining when a bed has been watered enough is by observing the shiny layer of water that forms on top of the soil. You will notice how the soil becomes shiny on the surface when watered. If the watering is stopped, the shiny layer will disappear quickly. The length of time that the "shiny" remains will tell you when the soil has received enough water. The shiny layer should remain for 5 to 15 seconds after you have stopped watering. This time will differ with different types of soil. The more clay a soil has, the less shiny it needs.

To see if you have watered correctly, in the morning go to the bed watered the previous day and push your finger into the soil. The first 2 inches (or a little below) should be moist. If the soil is dry for all or part of the first 2 inches, increase the shiny. If the soil feels soggy and very watery, shorten the shiny.

The farmer should learn to adjust watering with the weather. For example, a bed may lose more moisture on a cloudy, windy, dry day than on a clear, hot, humid day with no wind. When using sprinkler-type irrigation with movable pipes and rainers, a simple rain gauge made from a tin can is useful for determining how much water has been applied. Through experience, the farmer should note the amount of irrigation different crops need and measure application with a rain gauge placed in the irrigated area.

The successful farmer must learn to be sensitive to the needs of the crops and plants. Watering should be practiced for good vegetable and fruit production, and should not be the minimum just to keep plants alive. The farmer should come to know and understand the soils and crops upon which he or she depends. Just as each farmer is different, so is each crop, each soil, and each farm. Only the farmer can truly learn how to best care for his or her farm.

Planting—the placement of seeds and plants in the earth—is a basic skill for all farmers. The amount of care and thought given to this task will show in the yields and health of the farmer's crops.

## Sowing Seeds

Sowing seeds is a skill that all farmers and gardeners must master. Poorly sown seeds will result in poor, thin crop stands and cause the farmer more work. It is better to take time and care when sowing seeds to ensure good germination and less replanting.

A good guide to follow when planting seeds is to cover the seed with no more than twice its thickness of soil. When planting seeds in rows, a furrow should be made with a hoe. Then the seeds can be scattered thinly in the furrow and covered with a layer of soil or compost. The soil is then firmed slightly by patting with the hand or the blade of a hoe. This firms the soil and gives good contact between the seed and soil. Be careful not to pack the soil too tightly, because this will make it difficult for the young plants to come up through the soil.

There are three methods of sowing seeds used in intensive vegetable production: broadcasting, diagonal offset planting, and closely spaced rows.

## Broadcasting

Broadcast planting is the method of scattering seeds over the surface of the soil. Broadcasting is usually done by hand. Although broadcasting may require some practice before it is mastered, when properly performed, broadcasting can increase yields and extend the reaping season.

Most vegetables that are to be transplanted can be broadcast in the seedbeds. Carrots, mustard, turnips, and radishes give very good results when broadcast-planted.

Small seeds such as lettuce, cabbage, carrots, onions, and turnips should be broadcast so that the seeds will be 1 to 2 inches apart. If the seed is sown too thickly, some thinning of the young plants will be necessary. Carrots can be mixed with sand or cornmeal at the rate of 1 part seed to 8 parts sand or cornmeal. This mixture will help the farmer sow the seeds more evenly, so less thinning will be needed.

Broadcasting seeds allows the young plants to create and benefit from the living mulch—the "mini-climate" effect—much earlier in the season.

# Diagonal Offset Planting

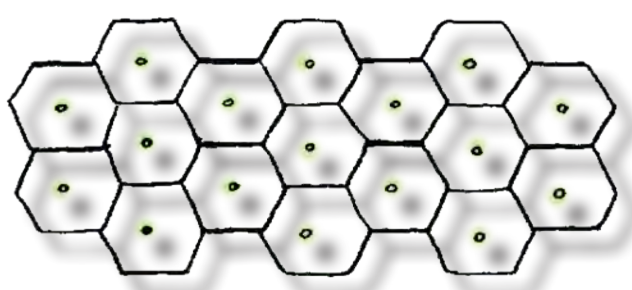
The diagonally offset pattern of planting may seem somewhat difficult for the beginning intensive gardener. A four-sided frame the width of the bed, made of small bamboo with 1-inch mesh chicken wire stretched across, will greatly simplify the seeding method.

**Figure 7-1: Chicken Wire for Use in Diagonal Offset Planting**

Photo c/o creativecommons.org

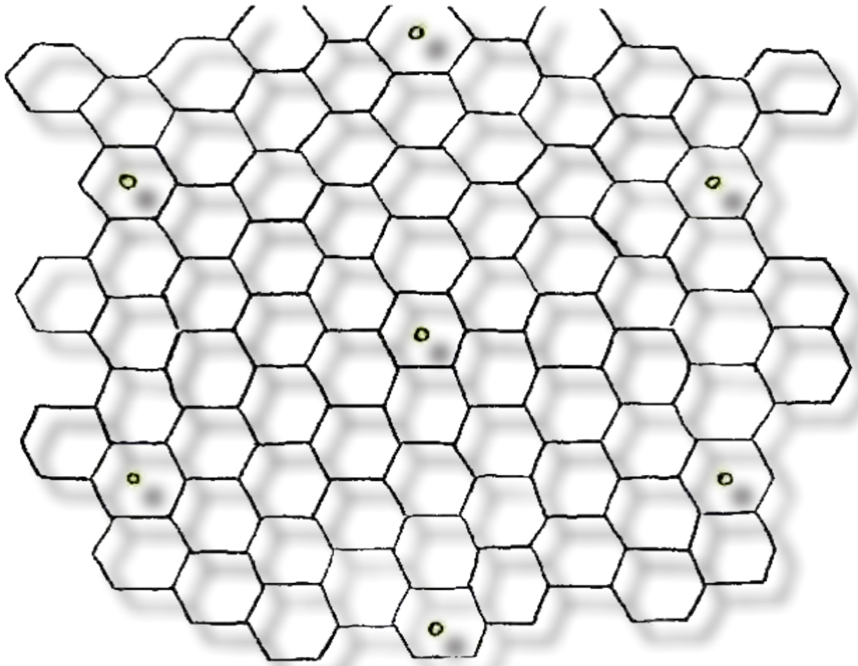
The 1-inch chicken wire is made in a hexagonal (six-sided) pattern. When planting seeds that are to be spaced 1 inch apart, the farmer drops one seed inside each hole of the mesh.

**Figure 7-2: 1-inch Spacing through Chicken Wire**



For seeds to be spaced further apart, for instance 4 inches, the farmer drops one seed, then counts four holes and drops the next seed.

**Figure 7-3: 4-inch Spacing through Chicken Wire**



Once the farmer is familiar with this method, he or she will find that it saves time and work. For example, less thinning will be required. This method makes the most intensive use of the growing space, with the plants covering the soil quickly and evenly.

## Close-row Planting

This method is a little easier than the diagonal offset method but usually requires more thinning of the young plants, which can be tedious and time-consuming work.

When planting rows on an intensive bed, it is best to plant across the width of the bed. Use Table 6-1 to determine spacing for the vegetables to be planted, and mark rows with a stick across the width of the bed. For example, if onion seeds are to be sowed, look on the chart to see that they are planted at 4-inch spacings. Mark the rows 4 inches apart, sow the seeds thinly in the furrows, cover them, and firm the seedbed by patting with the hand where the seeds were sown. The seeds should be sown so that they are 1 to 2 inches apart. After the plants are growing, they will be thinned out to one plant every 4 inches.

## Growing Transplants

Transplanting refers to removing young plants and planting them in a new place where they can grow to maturity. In this section, we have presented methods by which the farmer can produce strong transplants, and ways the farmer can reduce the shock of transplanting.

When growing seedlings to transplant, it is important to keep them growing strong and healthy. Strong transplants will increase yields.

### *Where to Grow Transplants*

To keep the young seedlings strong and healthy and ensure good germination of the seed, a well-prepared and fertile seedbed is an important step.

Seed can be sown in flats or trays, which can be moved and protected from harsh weather conditions or heavy insect attacks. Seed flats should be 3 inches deep by 14 inches wide and 23 inches long. If the flat or tray is too shallow, the young plants' roots will touch bottom too soon, causing the plants to age more quickly and slowing their growth

### *Soil for Growing Transplants*

A good soil mix for the seed flats is one part sand to three parts topsoil. This will ensure good germination and growth. If compost or well-rotted manure is available, some should be added to the mixture or spread on top of the seeds.

Seeds for transplants can also be sown in well-prepared seedbeds that have been refined and smoothed with a rake and enriched with fertilizer, manure, or compost. Seedbeds are usually made 4 feet wide and any length. The seeds are sown in rows 4 to 6 inches apart, across the width of the bed.

### *Spacing and Thinning*

It is important for the seedlings not to be crowded. Transplants that are grown too close together in the seedbed are weaker and more susceptible to disease and transplanting shock. Therefore, the seedlings should be thinned early to provide each seedling with enough room to grow.

Seedlings should be thinned when they have three or four leaves. Each seedling should have 4 to 6 inches between it and all other seedlings in the bed. Remember, crowded seedlings are weak seedlings.

## *Care and Watering*

When seedlings are grown during the hot part of the year, a simple shade structure will protect them from the burning sun and conserve moisture. A simple shade structure can be made from local materials such as coconut leaves, bamboo, or young trees. The roof should be tall enough to allow easy watering and working of the seedbed. The shade should not be too heavy, to allow some sun to come through. Each farmer must experiment to discover the key for best transplant cultivation on his or her farm.

Seedbeds should never be allowed to dry out completely. At the same time, the farmer/gardener must be careful not to overwater. Overwatering or watering late in the evening, before sunset, can cause damping-off disease in young seedlings. This fungus disease thrives in cool, moist areas. When a plant goes into the cool night with wet leaves and stems, chances of fungus attack increase.

Seedbeds and young plants may require watering two or three times a day. Always try to finish watering two to three hours before the sun goes down.

The gardener can produce stronger seedlings by watering them with liquid fertilizer or manure tea once a week. Liquid fertilizer can be made by adding 2 or 3 level tablespoons of a complete fertilizer, such as 10–10–10, to 3 gallons of water. Manure tea can be made by soaking rotted animal manure in water.

Transplants should be gradually exposed to sun one week before transplanting. Watering should also be gradually decreased to harden the plants in preparation for transplanting. To help the plant get a good start, 1 pint of manure tea can be applied immediately after transplanting.

## *Transplanting and Reducing Plant Shock*

On intensive raised beds, transplants should be planted in straight rows or in diagonally offset rows.

Straight rows across the width of beds are easier to lay out, but do not make as intensive use of the bed space as diagonally offset rows. Determine the spacing of the seeds. Then, rows are spaced that distance apart and spread out. Plants are then placed the same distance apart in the row. With time and experience, the gardener should be able to plant correctly without having to measure.

Diagonally offset rows make better use of the bed by allowing more plants to be planted in the bed. This method also gives a better total plant cover for the bed, providing the living mulch effect. With plants such as celery and onions, a wire mesh frame can be used as a guide to mark the spot where each plant is to be planted. For plants that should be planted further apart, such as cabbage and lettuce, measuring sticks of the desired distance can be used to determine where each plant should be placed.

The greatest problem in transplanting is the shock of uprooting the plant. When a young plant is removed from the soil, it suffers greatly. It is up to the farmer/gardener to do all he or she can to ease the shock and promote the quick recovery of the young plant.

When removing seedlings from the seedbed, the greatest damage and shock is to the roots. These are where the plant takes in its food. If the roots are exposed to air, sun, or rough handling, many of them will be destroyed. Remember from Chapter 1 that the root hairs, which are nearly invisible to the human eye, absorb nutrients for the plants. If root hairs are damaged or shocked in transplanting, they stop absorbing food for the plant, and the plant's growth slows. The intensive market gardener must develop the transplanting skill to ensure good yields and early bearing. Transplanting, and the time it takes the plant to recover, affects how soon the crop will mature and how soon it can be reaped. These are very important facts to the intensive market gardener who wishes to catch an early market, when prices are high.

One way to minimize transplanting shock is to have strong, healthy, growing plants. Plants that have been crowded or have slowed or stopped growing are poor transplants and will give poor yields. Transplant seedlings before this happens. The timing of transplanting is critical for strong plants and high productivity.

To keep the plants growing and healthy, high-quality and abundant plant foods must be provided for transplants. If these are provided, transplanting a plant can actually help it grow faster. Just put some in the planting hole. It is important to remember that beds should be prepared and fertilized before the plants are transplanted into them.

Before removing seedlings from the bed, the bed should be thoroughly watered. This will help keep more soil around the roots and reduce root damage.

Seedlings are fragile. It is important to handle them as little as possible. The seedlings should be held by the tips of their leaves or by the soil around their roots. Removing seedlings from beds or flats should be done with the help of a hand fork. Gently loosen and take up a 4-inch section or square of soil and plants. This section should be placed on the ground; then one plant at a time should be gently pulled away for transplanting. If the day is hot, dry, or windy, the seedlings should be protected by wrapping them with a wet paper bag. The planter should always strive to keep as much soil around the roots as possible.

When transplanting the seedlings, make holes large enough that the plant can be set a little deeper than it was in the seedbed or flat. This will insure that the upper roots do not become exposed. The soil should be pressed firmly around the plant, but not too tight. Soil packed too tightly can damage the roots and prevents water, air, and nutrients from reaching the roots. Soil that is too loose around the roots will allow too much air and water to gather around the roots, causing root burn and decay. Firm contact of the roots with the soil will help the plant roots absorb nutrients and water.

When setting transplants, be certain they are placed deep enough that they will not bend over. Cabbage seedlings should be planted up to their first two leaves. Plants that bend over will develop very tough stems, which reduce the size and quality of the vegetables they will produce.

After seedlings are planted, they should be watered-in. Manure tea or liquid fertilizer can be used to water-in the transplants. About a pint per plant should be enough. This gives the plant a quick boost of strength to help overcome the shock of transplanting. Watering helps remove air pockets around the roots and prevents the roots from drying out. The growing bed where the plants are to be transplanted should also be watered before planting. This will do much to help the transplants "catch." Seedlings transplanted into dry soil will dry quickly and thus require watering sooner and more often.

Cloudy days with no wind are the best days for transplanting. Late afternoons and evenings are the best times of day to transplant.

**Figure 7-4: Transplanting**

1. Soak the soil around seedlings before removal.

2. Loosen soil around seedlings with a hand tool.

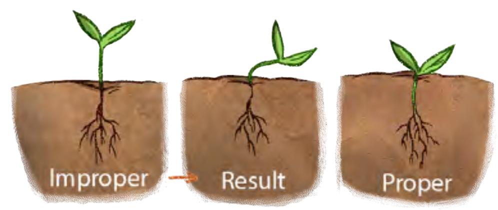
3. If seedling is in a pot, carefully turn upside down, holding plant between second and third finger, and tap pot with other hand.

4. When handling seedlings, hold by two leaves or...

5. ...hold by ball of roots in the palm of your hand.

6. Make sure the hole is big enough for the root system.

7. Plant deep enough.




8. Water in the seedlings after transplanting.

## Companion Planting

A good example of companion planting is cucumbers and corn. Cucumbers grow best with some shade. This shade is provided by growing cucumbers under corn. The corn also benefits from the cucumber vines, which cover the ground like living mulch. Another example of this type of companion planting is with lettuce. Lettuce benefits from the shade of taller crops such as tomatoes or eggplant, which also have deeper root systems than the lettuce. This gives the farmer two crops where he or she usually grows only one! The ability of companion crops to survive and produce on the same land where only one crop is usually planted is important to the intensive market gardener. It allows him or her to intensify the garden and produce more from the same land area. By planting crops that help each other grow and resist insects together, the gardener exhibits another skill in using nature to ensure the productivity and health of the garden.

Figure 7-5: Companion Planting

Photo c/o creativecommons.org

Certain plants do poorly when planted together. Some plants, such as sunflowers, give off substances that slow the growth of any plants growing near them. The intensive market gardener should take notice of plant relationships in the garden. He or she should experiment to utilize the companion crops that work best in the circumstances. Again, the farmer must learn to be a scientist, to experiment and learn through his or her experience.

Interplanting or intercropping is a form of companion planting. Companion planting is based on the benefit that one crop gets by being planted near another crop. The importance of interplanting is that total production can be increased by planting two crops on the same piece of land at the same time. This long-standing practice can be observed all over the world, including in China, India, Jamaica, Japan, Nigeria, and the United States.

It has recently been proven that a field interplanted with corn and soybeans can yield a full crop of corn and three-quarters of a full crop of soybeans. In the experiments, corn was planted as usual in rows, and two rows of soybeans were planted between each row of corn. The yields were compared with the yields of pure stands of corn and soybeans. Three-quarters of a soybean crop means that the interplanted soybean crop yielded less than a pure stand. However, the soybeans were a bonus, because a full crop of corn was harvested! Looked at in this way, one acre of interplanted corn and soybeans yielded as much as one acre of corn and three-fourths acre of soybeans. The acre that was intercropped produced nearly twice as much as two acres that were planted with single crops.

Thus, intercropping is yet another method that the skillful farmer can use to make more intensive and productive use of the land. The corn-soybean experiment also demonstrates how the farmer can learn through experimentation on his or her crops and land. To be successful, a farmer must learn both from the relevant experiences of others and from his or her own experiences.

## Succession Planting

Succession planting is the planting of a crop in a field or bed immediately after another crop has just been reaped. This practice makes intensive use of the land by keeping it under cultivation at all times.

Succession planting requires good planning and timing. For example, if a crop of green beans were to be followed by a crop of lettuce, the gardener would have to plan and plant so that the lettuce seedlings would be ready to transplant when the beans have been reaped.

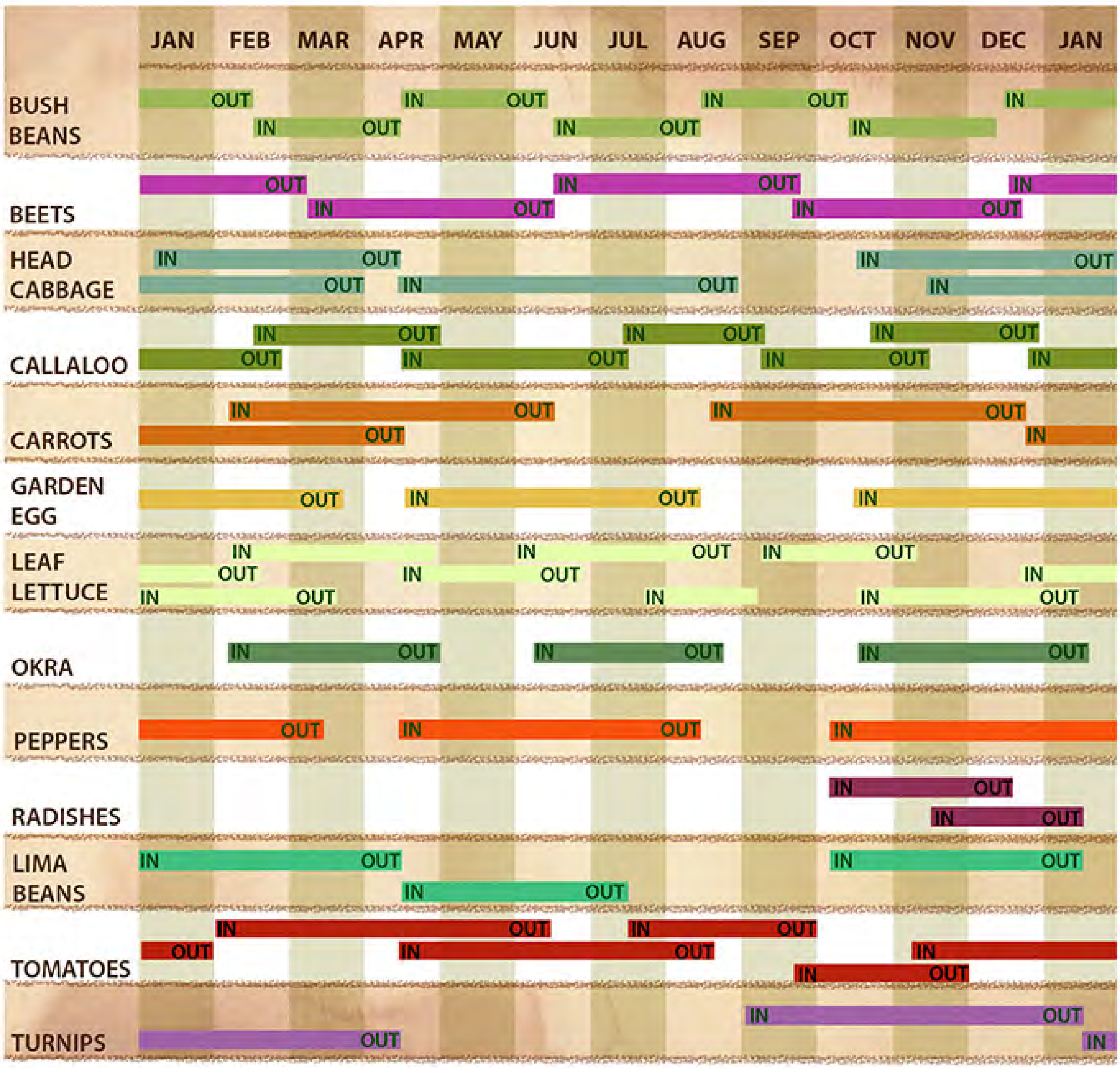
An important part of this method is the quick preparation and fertilizing of the vegetable bed. It is here that a power hand tractor can be useful on raised beds to improve land productivity. With a power hand tractor on beds that have been forked and double-dug for the first crop, the time required for re-preparation of the beds will be greatly reduced. However, even with hand labor, the preparation time is never as great on the second cropping as it was for the first.

The key to succession cropping is careful planning. A planting chart will greatly simplify planning. To make a succession-planting chart, first list all the crops to be grown. Then determine when each crop will be planted and the length of time and estimated date of harvest.

Making two or three staggered plantings of the same crop can also be part of a succession-cropping plan. This will extend the crop season for gardeners who wish to have fresh vegetables stretched over a longer season.

The following chart is an example and will vary depending on the local environment.

**Table 7-1: Succession-planting Chart for a Vegetable Garden at Elevation between Sea Level and 1,000 Feet, with a 12-month Growing Season**




For instance, staggered plantings of carrots—sowed three times with each sowing a week or so apart— can also benefit the market gardener. It saves labor because the entire crop does not have to be reaped at one time. In addition, the late crop may reach the market when the season is ending and prices are usually higher. The longer reaping season gives the market gardener the advantage of having a reliable supply of produce over a longer period. This allows the gardener to establish and supply markets where buyers prefer fresh and reliable produce.

From the succession-planting chart above, the gardener can see when crops can be harvested and others planted. An up-to-date succession-planting plan allows the gardener to see when beds will be empty and which crops can be planted in them.

For instance, the first crop of cabbage can be reaped in April. By looking at the chart, the gardener can see that April is the month to plant carrots, string beans, and lettuce. Therefore, the area that was planted with cabbage can be planted to one of these three crops.

Soil fertility is a critical element in successful succession planting. Because succession planting keeps the land under continual cropping, it takes much fertility out of the land. Fertility must be returned if the productivity is to be maintained. If this is done, succession planting can double and triple a farm's production!

## Crop Rotation

Crop rotation is the planting of different crops in sequence on a piece of land. Crop rotation is a good farming/gardening practice for several reasons.

A most common reason for crop rotation is that it inhibits the growth and spread of insects and diseases that are destructive to crops. Insects and diseases usually prefer to feed and breed in certain crops or families of crops. Planting the same crop in the same land every year allows insects and disease to build up in that area. Planting a crop that the insects and disease do not attack causes them to die off or move to another area. At that point, the first crop could be replanted if the farmer desires.

Another good reason for crop rotation is that different crops take different minerals from the soil. Also, different crops' roots feed in different areas of the soil. By rotating crops, the land is not depleted and is given a rest. In addition, crops such as legumes (cow peas, red peas) add nutrients back to the soil.

## Crop Types and Families

Crops can generally be divided into three groups according to their feeding habits: heavy feeders, light feeders, and heavy givers. For conservation of soil fertility, a heavy feeder, such as tomatoes, should be followed by a heavy giver, such as cow peas, to return nitrogen to the soil. A light feeder, such as turnips, should be planted to give the soil a rest before the next heavy feeders are planted. The proper rotation of crops based upon their characteristics is an important part of a total soil management program. It helps build as well as maintain soil fertility. It also helps control diseases and insects that attack the crops, reduce productivity, and increase the costs of cultivation and pest/disease control.

In the following tables, some of the common vegetables and pulses are listed according to their feeding habits and families, and samples of rotation patterns that will be generally healthy for the soil and crops.

**Table 7-2: Common Crops and their Feeding Habits**

| Heavy Feeders | Light Feeders | Heavy Givers |
|---|---|---|
| Broccoli | Turnips | Broad beans |
| Cabbage | Beets | Cow peas |
| Cauliflower | Carrots | Gungo peas |
| Corn | Sweet potatoes | Legumes |
| Cucumbers | Radishes | Soybeans |
| Eggplants | Root crops | String beans |
| Melons | Red peas | |
| Peppers | | |
| Pumpkins | | |
| Tomatoes | | |

**Table 7-3: Crop Families**

| Tomato | Melon | Cabbage | Legume |
|---|---|---|---|
| Garden eggs | Cucumbers | Broccoli | Broad beans |
| Irish potato | Pumpkins | Cabbage | Cow peas |
| Peppers | Squash | Cauliflower | Gungo peas |
| Tomatoes | Watermelons | Chinese cabbage | Red peas |
| | | Mustard | Soybeans |
| | | Turnips | String beans |

**Table 7-4: Examples of Crop Rotations**

| | Crop 1 | Crop 2 | Crop 3 |
|---|---|---|---|
| A | Corn | Red peas | |
| B | Cabbage | String beans | Turnips |
| C | Lettuce | Cow peas | Carrots |
| D | Pumpkins | Red peas | Sweet potatoes |
| E | Peppers | Soybeans | Beets |

## Conclusions on Planting

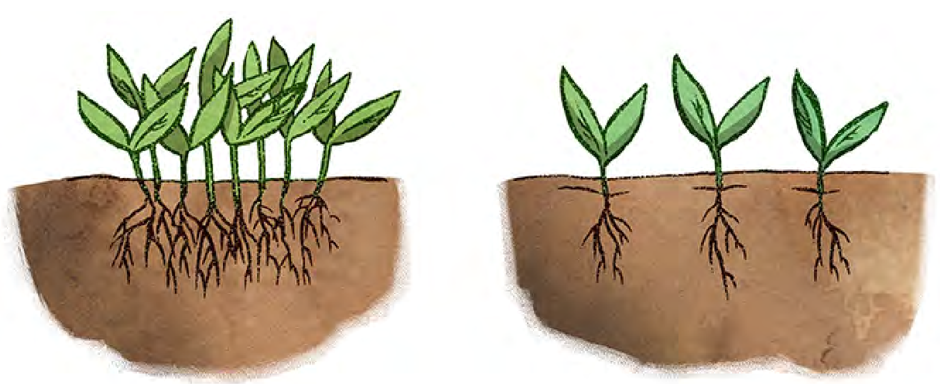
Planning is important for crop rotation, so the farmer can look at the plan for his or her land and see where each crop is planted and its timing for harvesting, cultivation, watering, and re-planting. Through carefully organized plans, proper rotations can be maintained.

Planning and planting are skills that work together for the farmer. They help the farmer get maximum production from the land. The wise use of a variety of planting methods helps the farmer produce healthier crops through a longer reaping period. Good planning and planting, as in crop rotation, also helps the farmer maintain the fertility and health of the soil, which is in the farmer's interest for present and future profit and productivity.

**Figure 7-6: Gardening Tips**

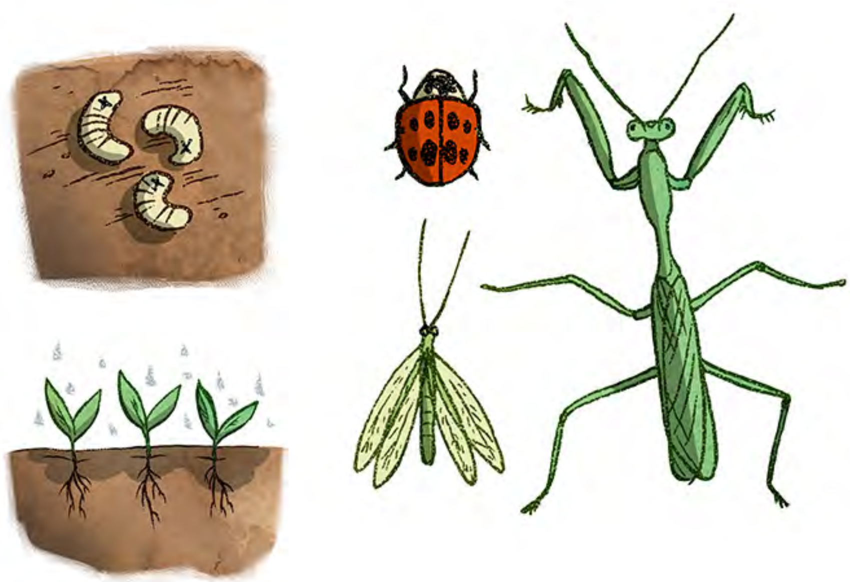
*Keep garden clean of weeds and old weed piles.*

*Keep plants thinned to desired spacing.*



*Hand pick insects and eggs. Sprinkle wood ash against flea beatle.*

*Kill grubs and keep soil moist. Attract good insects like lady beatles, lacewings, and praying mantises.*



## Cultivation

Cultivation is an important task that should not be neglected or postponed. Good cultivation requires constant attention to the health of the crops, the conditions of the soil, and the total environment in the garden setting. Cultivation generally refers to the land-tilling operations that remove weeds and break up the crust of the soil to encourage maximum plant growth. Cultivation can also refer to the entire process of planting, tending, and harvesting a crop. However, the good garden cultivator will see the task of cultivation as a concern for the total health of the garden, so that he or she looks for indications of disease and insects, decreased soil fertility, and plant starvation throughout the total growing season.

Removal of weeds is, of course, an important task of cultivation. Removing weeds when they are young will be less work and will prevent root damage to the crop. The farmer who lets weeds grow large shows a lack of skill and interest in the garden.

Cultivation comprises two tasks: removing weeds from the soil and loosening the top 2 to 3 inches of soil. However, these tasks must be seen as only a part of cultivation, which is really the ongoing attention that the farmer gives to the growing crop.

The importance of cultivation is clear. It protects plant health and promotes high productivity. Destroying weeds that would rob nutrients from the soil increases yields. Shallow cultivation of the top 2 to 3 inches of soil forms a soil mulch to conserve moisture. The surface of the soil tends to form a crust. Light cultivation breaks up this crust and improves the soil's capacity to absorb water and air for the plants. Without good supplies of air and water, the vegetable beds cannot be highly productive, and plants that must compete with weeds for nutrients are not high producers.

The best time to cultivate is one or two days after a good rain or irrigation. Working land too soon after rain or irrigation, or when the soil is muddy, will destroy the structure of the soil. This makes it more difficult for plants to grow.

For the cultivation of row crops, a power hand tractor, push wheel hoe, or regular hand hoe can be used. Care should be taken not to cultivate deeper than 1 to 2 inches and to avoid coming too close the roots and stems of the crops. When using a power hand tractor, rows of crops should be spaced wide enough that the tractor can pass between the plants without damaging the roots.

For the intensive market gardener who uses raised beds, small hand cultivators are very useful. They allow the farmer to cultivate between closely spaced plants. In intensive bed gardening, the farmer will find that less cultivation will be needed, because the bed is quickly covered with the leaves of the crop and the shading effect keeps out weeds. Another advantage of a properly prepared raised bed is that the weeds' roots pull out of the loose soil easily. Less weeding is required, because the entire weed and its root are removed. After several seasons, the beds will have very few weeds, further reducing the need for this type of work.

## Garden Tools

Good tools are essential to the professional market gardener. Good tools must be cared for diligently so they will last. In the tropics, it is important to clean and oil tools regularly, because the humid climate is very destructive to the materials. Tools should be carefully oiled before storing. Old motor oil can be used to oil the metal parts of spades, rakes, hoes, and forks. Tools should be cleaned regularly and after every use. Good tool care will prevent the tools from being damaged by rust and will help them last longer. Taking care of tools reduces costs.

Some sort of simple shelter should be provided to protect the tools when they are not being used. A thatched hut with thatched walls located near the garden area is convenient for storing tools, fertilizers, and sprays. A hut also provides good protection for the gardeners and workers in times of rain or intense heat.

The following tables list a number of useful and necessary tools for the market gardener.

**Table 8-1: Useful and Necessary Tools for the Market Gardener**

| Tool | Description |
|---|---|
| Fork | A four-pointed spading fork for loosening or plowing the ground |
| D-handle spade | A D-handled, square-pointed spade for double-digging raised beds, digging trenches, and shoveling manures, compost, and soil |
| Hand spade | A small spade used with only one hand; useful for working with young transplants or seedlings |
| Hand fork | A small fork used in only one hand; good for taking up small seedlings and transplants |
| Hand cultivator | A claw-shaped hand tool for cultivating seedbeds and intensively planted raised beds |
| Shallow weeding hoe | A long-handled hoe that works well for cultivating weeds and working with row crops |
| Heavy-duty hoe | A short-handled hoe that works well for breaking up large clods of soil or hoeing up sides of beds |

| Tool | Description |
| --- | --- |
| Wheelbarrow/two-wheel cart | Useful for transporting manure, compost, fertilizers, tools, and vegetables; saves the gardener much time and labor |
| Sickle | A good tool for cutting grasses or grains; can be used in place of machetes effectively for such work |
| Stake and lines | A good set of solid stakes and strong line are invaluable in measuring distances and marking out beds or rows |
| Watering can | Good for watering seedlings and other tender crops, and for intensive beds |
| Wheel hoe | A useful tool for cultivating row crops |
| Seed planter | A helpful tool for seeding crops that will be planted in rows |

**Figure 8-1: Tools**

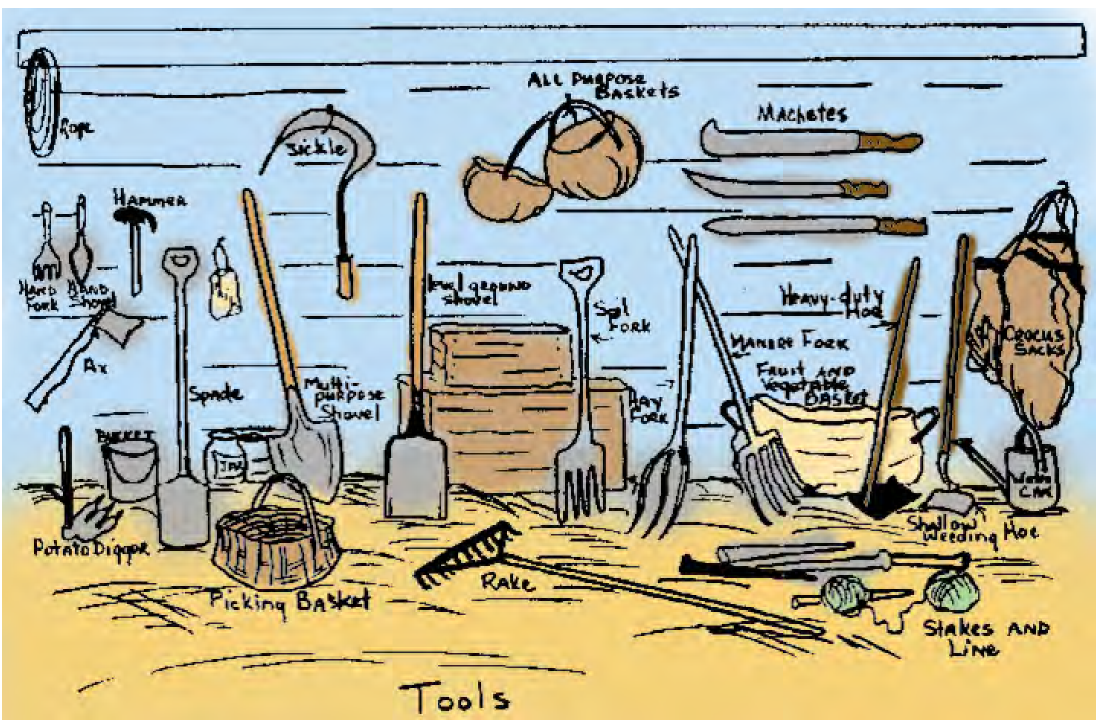


**Figure 8-2: Wheel Hoe**

Photo c/o creativecommons.org

**Figure 8-3: Seed Planter**

Photo c/o creativecommons.org

## Sprayers

Sprayers come in many sizes and designs. For the professional market gardener, a large backpack sprayer with a hand-operated pump or a gas engine-powered pump is best.

With good care and maintenance, these sprayers will give long service. After each use, the sprayer should be cleaned and placed upside-down so any moisture will run out. A strainer usually comes with the tool to remove any debris or trash from the spray liquid. When cleaning the sprayer thoroughly, it is best to pump clean water through it. Remember, also, to take the nozzle apart and clean it carefully.

**Figure 8-4: Types of Sprayers**

Photo c/o creativecommons.org

*Shown, from left, are a backpack sprayer, pressurized sprayer, and motorized backpack sprayer.*

## Power Hand Tractors

These machines are very useful to the professional market gardener. Although the use of power hand tractors has been discussed in a previous chapter, we re-emphasize their value and potential uses here.

The most useful design of the power hand tractor is one in which the wheels, as well as the tines or tillage implements, are driven by the engine. This design is much easier to operate than other types, and is more adaptable to different garden locations. It can be maneuvered easily on hillsides as well as on terraces and beds.

Power hand tractors often have many useful attachments. For example, there is a 40-inch sickle bar mower that can be used to cut grass on hillsides for mulch or hay. Other attachments include a small irrigation pump, an electricity generator, and two-wheel carts for pulling loads.

All farmers who own or operate these machines should understand proper care and maintenance of the equipment and engines. Although maintenance manuals are available, the development of these skills does not require the ability to read or write. One can learn to care for machines through observation, demonstrations, and common sense. Short demonstrations or demonstration courses are invaluable for learning machine maintenance and care. For machines to make a truly lasting impact on agriculture and to be a valuable investment for the farmer, maintenance is necessary!

## Shredder-grinder

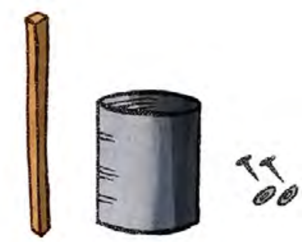
The shredder-grinder is a small machine, powered by a gas engine, that can shred and grind organic materials such as leaves, twigs, branches, straw, grass, bark, and manures. Shredding and grinding organic materials helps them decompose more quickly for the garden. Mature, ready-to-use compost, can be produced in 14 days. If a large amount of grass and manure is available, this is a great help. It helps the farmer maintain soil fertility at the high levels necessary for intensive gardens and continuous cropping.

**Figure 8-5: Shredder-grinder**

Photo c/o creativecommons.org

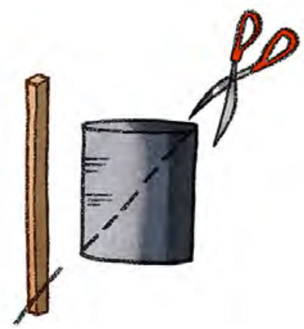
**Figure 8-6: How to Make a Hand Shovel with a Tin Can**

**Materials needed:**



- 1-inch square piece of wood 9 inches long. This will be used for the handle.
- 1 tin can (like a juice can). The size of the can will determine the size of your shovel (handle size will change with a different size can).
- 2 flathead nails
- 2 washers

**Steps:**



1. Cut one end of the wood to a 45-degree angle. (This angle will line up with the cut made on the can.)

2. Cut the can diagonally in half. (Take note that you do not cut either end of the can.)

3. The wooden handle goes flat against the can. Place pointed end of wood at pointed end of can.

4. From the inside of the can, place the washer with the nail, lining them up with the middle of the handle.


5. Hammer the nail through the can and well into the wooden handle. Place the second washer and nail 1 inch away and hammer in.

## Pest Management

It is not within the scope of this manual to provide a detailed discussion on insect and disease control. There are many publications available on insect and disease management. The farmer/gardener should acquaint himself or herself with information on this important subject. The skillful farmer must develop a keen awareness concerning the nature of insects and diseases.

## Natural Controls of Insects and Diseases

The farmer should learn to observe the actions and life cycles of insects in the garden and surrounding areas. By observing nature, the farmer will learn which insects are harmful and which are helpful. He or she will discover that some insects help by eating the insects that are harmful to the plants. The gardener with a watchful eye will soon discover the breeding places of pests and diseases and will be able to remove or destroy them. Control of breeding places will do much to keep down pests.

All trash and crop waste should be composted. If any material is diseased, it should be burned first. This is a key step in pest management. No time should be wasted in doing this. The longer waste stays on the land, the more insects will build up in it.

The farmer must realize that healthy, well-fed plants are less likely to be attacked by disease and insects. Just as poorly fed people cannot survive well and are too weak to fight off attacks of sickness, neither can a weak plant survive well or fight off attacks from insects or diseases. It is wise for the farmer to spend time on providing a balanced diet of nutrients for the crops. He or she must pay close attention to the health and fertility of the soil in which the plants live. Unhealthy plants often mean that the soil is unhealthy too!

## Spraying

Farmers could become acquainted with the local agriculture officer, who has information concerning pest control and the use of chemical sprays. Spraying should be done exactly as recommended by the officer. Some sprays have very strict rules to follow, because they are dangerous to the health and well-being of people, animals, and the environment.

The farmer must take steps to join hands with nature. Local information available from the agricultural officer will help the farmer devise a good control system for crops. By including nature in the fight against pests and diseases, the farmer will have many insects working with him or her, providing more natural control of the population of harmful insects.

## Summary

Farmers the world over are becoming aware of the fact that proper maintenance of soil fertility and soil structure will help reduce pest damage. Organic matter increases the population of a soil microbe that gives off ethylene gas, which kills fungus.

Pest control is very important to the farmer. The health of the crops and fertility of the soil is an important part of this. Careful, skillful use of chemical sprays will also require the attention and study of the serious farmer.

The best pest management program is one in which the farmer strives for healthy, pest- and disease-resistant plant growth by providing a healthy, balanced soil fertility and treats any damaging pests with careful, studied use of chemical sprays.

# Appendix A: Useful Information for Planting Vegetables

**Table A-1: Seeds per Ounce and Germination Rates[5]**

| Seeds Per Ounce | Germination Rate (Percentage) |
|---|---|
| Bush beans 100 | 75 |
| Pole beans 100 | 75 |
| Bush lima beans 20–70 | 70 |
| Pole lima beans 20–70 | 70 |
| Beets 1,603 | 65 |
| Broccoli 9,000 | 75 |
| Cabbage 8,500 | 75 |
| Carrots 23,000 | 55 |
| Cauliflower 10,000 | 75 |
| Celery 70,000 | 55 |
| Swiss chard 1,200 | 65 |
| Chinese cabbage 9,500 | 75 |
| Corn 100–200 | 75 |
| Cow peas 125 | 75 |
| Cucumbers 1,000 | 80 |
| Eggplant 6,000 | 60 |
| Lettuce 25,000 | 80 |
| Melons 1,200 | 75 |
| Okra 500 | 50 |
| New Zealand spinach 350 | 40 |
| Onions 9,500 | 70 |
| Parsley 18,000 | 60 |
| Peppers 4,500 | 55 |
| Pumpkins 110 | 75 |
| Radishes 2,000 | 75 |
| Tomatoes 11,000 | 75 |
| Turnips 13,000 | 80 |
| Watermelon 225–300 | 70 |
| **Special Planting Guide** | |
| Bush beans | |
| Pole beans | |
| Bush lima beans | Plant two seeds per center, thin out extra plants. |
| Pole lima beans | |

5 Germination rates for Table A-1 are from studies of seeds in Jamaica in the 1970s. Germination rates could vary significantly depending on seed variety, soil properties, environmental conditions, and other factors.

# Appendix A: Useful Information for Planting Vegetables

| Seeds Per Ounce | Germination Rate (Percentage) |
|---|---|
| Corn | |
| Swiss chard | |
| Carrots | |
| Beets | Plant two seeds per center, thin out extra plants. |

**Table A-2: Spacing for Intensive Method of Growing Plants in Bed Crop Spacings**

| Crop | Spacing |
|---|---|
| Broad beans | 8″ |
| Bush beans, green | 4″ |
| Pole lima beans | 8″ |
| Bush lima beans | 8″ |
| Pole beans | 6″ |
| Beets | 3″ |
| Broccoli | 14″ |
| Cabbage | 14″ |
| Carrots | 2″ |
| Cauliflower | 15″ |
| Celery | 6″ |
| Chard | 8″ |
| Chinese cabbage | 10″ |
| Cucumbers | 12″ |
| Garden eggs | 18″ |
| Kale | 15″ |
| Lettuce | 12″ |
| Leaf lettuce | 8″ |
| Mustard | 6″ |
| Okra | 12″ |
| Onions | 3″ |
| Parsley | 4″ |
| Peppers, hot | 16″ |
| Sweet | 12″ |
| Radishes | 1″ |
| Spinach | 2″ |
| Tomatoes | 24″ |
| Turnips | 3″ |

**Table A-3: Planting Centers per 100 Square Feet**

| Spacing | Centers |
|---|---|
| 1″ | 14,400 |
| 2″ | 3,600 |
| 1″ | 1,600 |
| 4″ | 900 |
| 6″ | 400 |
| 8″ | 225 |
| 9″ | 178 |
| 10″ | 144 |
| 12″ | 100 |
| 15″ | 56 |
| 18″ | 44 |
| 24″ | 25 |
| 30″ | 16 |
| 72″ | 3 |

**Table A-4: List of Common Garden Vegetables with their Companions and Antagonists**

| Vegetable | Likes | Dislikes |
|---|---|---|
| Beans | Potatoes, carrots, cucumbers, cauliflower, cabbage | Onions |
| Pole beans | Corn | Onions, beets, sunflowers |
| Beets | Onions | Pole beans |
| Cabbage<br>Cauliflower<br>Kale<br>Broccoli | Thyme, peppermint, rosemary, potatoes, celery, beets, onions, scallions, garlic | |
| Carrots | Tomatoes, beans, cauliflower, cabbage | |
| Corn | Potatoes, peas, beans, cucumbers, pumpkin, squash | |
| Cucumber | Beans, corn, peas, radishes | Potatoes |
| Garden eggs | Beans | |
| Lettuce | Carrots, radishes | |
| Onions | Beets, tomatoes, lettuce | |
| Parsley | Tomatoes | |

# Appendix A: Useful Information for Planting Vegetables

| Vegetable | Likes | Dislikes |
|---|---|---|
| Peas | Carrots, turnips, radishes, cucumber, corn, beans | |
| Potatoes | Beans, corn, cabbage | |
| Pumpkins | Corn | Potatoes |
| Soybeans | *Helps everything grow better!* | |
| Tomatoes | Onion, parsley, carrots | Cabbage |
| Turnips | Peas | |

**Table A-5: Time Required to Raise Vegetable Seeds to Transplanting Size (timing may vary by environment)**

| Crops | Weeks |
|---|---|
| Broccoli | 4–6 |
| Brussels sprouts | 4–6 |
| Cabbage | 4–6 |
| Cauliflower | 4–6 |
| Celery | 8–12 |
| Garden eggs | 6–8 |
| Onions | 10–12 |
| Peppers, sweet | 6–8 |
| Tomatoes | 6–8 |

**Table A-6: Seeds for Beds and Transplant**

| Seeds to start in planting beds | Seeds to plant in seedbeds and transplant |
|---|---|
| Bush beans, beets, carrots, chard, radishes, spinach, turnips | Broccoli, Brussels sprouts, cabbage, cauliflower, celery, garden eggs, lettuce, onions, peppers |

**Table A-7: Cool Season and Warm Season Crops**

| Seasonal Temperatures | 55° | 60° | 70° | 75° | 80° | 85° | 90° |
|---|---|---|---|---|---|---|---|
| Cool Season Crops | Cauliflower, Spinach | | | | | | |
| | | Broccoli, Chinese cabbage, Celery, Radish, Collards, Kale*, Garlic, Head lettuce, Turnips | | | | | |
| | | Beet, Bulb onion, Cho-cho, Carrot, Leaf lettuce**, Mustard, Irish potato | | | | | |
| Year-Round Growing Crops | | Cucumber, Scallion, Squash, Muskmelon, Leek | | | | | |
| | | Beans, Chard, Corn, Parsley, Cowpea, Red pea, Sweet and Hot pepper, Soybean, New Zealand spinach, Yam, Callaloo, Tomato | | | | | |
| Warm Season Crops | | | Garden egg, Pumpkin, Sweet potato, Okra, Watermelon, Muskmelon | | | | |

** Kale has been known to survive drought conditions.*

*** Leaf lettuce may be grown in warmer temperatures with some shading.*

**Table A-8: Estimated Yields per 25-foot Row**

| Crop | Yield |
|---|---|
| Bush beans, green | 12 pounds |
| Bush beans, lima | 6 pounds |
| Beets | 20 pounds |
| Broccoli | 8 pounds |
| Chinese cabbage | 18–30 heads |
| Head cabbage | 12–25 heads |
| Carrots | 20 pounds |
| Cauliflower | 16–20 heads |
| Celery | 35–50 heads |
| Chard | 25 pounds |
| Corn | 30 ears |
| Cucumbers | 30 pounds |
| Garden eggs | 50 pounds |
| Kale | 15 pounds |
| Kohlrabi | 15 pounds |
| Head lettuce | 20–25 heads |
| Leaf lettuce | 25–30 bunches |
| Mustard | 25 pounds |

| Crop | Yield |
|---|---|
| Okra | 30–40 pounds |
| Bulb onions | 25–30 pounds |
| Scallions | 10 pounds |
| Parsley | 5 pounds |
| Sweet peppers | 15 pounds |
| Potatoes | 20 pounds |
| Pumpkins | 30–40 pounds |
| Radishes | 20 dozen |
| New Zealand spinach | 10 pounds |
| Squash | 30–45 pounds |
| Tomatoes | 50 pounds |
| Turnips | 10–15 pounds |
| Watermelons | 100 pounds |

**Table A-9: Estimated Yields per 100-square-foot Bed**

| Crop | Yields |
|---|---|
| Bush beans, green | 48 pounds |
| Bush beans, lima | 24 pounds |
| Beets | 80 pounds |
| Broccoli | 32 pounds |
| Chinese cabbage | 72–120 pounds |
| Head cabbage | 48–100 pounds |
| Carrots | 80 pounds |
| Cauliflower | 64-80 heads |
| Celery | 140-200 heads |
| Chard | 100 pounds |
| Corn | 120 pounds |
| Cucumbers | 125 pounds |
| Garden eggs | 200 pounds |
| Kale | 60 pounds |
| Kohlrabi | 60 pounds |
| Head lettuce | 80–100 heads |
| Leaf lettuce | 100–120 bunches |
| Mustard | 100 pounds |
| Okra | 120–160 pounds |

| Crop | Yields |
|---|---|
| Bulb onions | 100–120 pounds |
| Scallions | 40 pounds |
| Parsley | 20 pounds |
| Sweet peppers | 60 pounds |
| Potatoes | 80 pounds |
| Pumpkins | 120–160 pounds |
| Radishes | 80 dozen |
| New Zealand spinach | 40 pounds |
| Squash | 120–180 pounds |
| Tomatoes | 200 pounds |
| Watermelons | 400 pounds |
| Red peas | 12 pounds |
| Rice | 16 pounds |

**Table A-10: Row Crop Spacings**

| Crops | Inches Spaced |
|---|---|
| Bush beans, green | 3–6 |
| Bush beans, lima | 6–8 |
| Beets | 2–3 |
| Broccoli | 15–18 |
| Chinese cabbage | 6–12 |
| Head cabbage | 12–24 |
| Callaloo | 10–12 |
| Carrots | |
| Cauliflower | 15–1.8 |
| Celery | 6–12 |
| Chard | 6–12 |
| Corn | 12–16 |
| Cucumbers | 24–36 |
| Garden eggs | 10-30 |
| Kale | 15–20 |
| Kohlrabi | 10–18 |
| Leeks | 5–10 |
| Head lettuce | 12–15 |
| Leaf lettuce | 6–12 |

# Appendix A: Useful Information for Planting Vegetables

| Crops | Inches Spaced |
|---|---|
| Mustard | 4–6 |
| Okra | 12–15 |
| Bulb onions | 4–6 |
| Scallions | 4–6 |
| Parsley | 4–6 |
| Peppers, hot and sweet | 12–16 |
| Potatoes | 12–14 |
| Pumpkins | 30–36 |
| Radishes | 1–2 |
| New Zealand spinach | 10–12 |
| Squash | 36–48 |
| Tomatoes | 24–48 |
| Turnips | 3–6 |
| Watermelons | 36–48 |

**Table A-11: Estimated Yields per Acre of Intensely Planted Ground**

| Crop | Yields |
|---|---|
| Bush beans, green | 19,000 pounds |
| Bush beans, lima | 9,600 pounds |
| Beets | 32,000 pounds |
| Broccoli | 12,800 pounds |
| Chinese cabbage | 36,000 pounds |
| Head cabbage | 30,000 pounds |
| Carrots | 32,000 pounds |
| Cauliflower | 28,000 heads |
| Celery | 68,000 heads |
| Chard | 40,000 pounds |
| Corn | 48,000 pounds |
| Cucumbers | 24,000 pounds |
| Garden eggs | 80,000 pounds |
| Kale | 24,000 pounds |
| Kohlrabi | 24,000 pounds |
| Head lettuce | 36,000 heads |
| Leaf lettuce | 48,000 bunches |
| Mustard | 40,000 pounds |

# Appendix A: Useful Information for Planting Vegetables

| Crop | Yields |
|---|---|
| Okra | 56,000 pounds |
| Bulb onions | 48, 000 pounds |
| Scallions | 16,000 pounds |
| Parsley | 8,000 pounds |
| Sweet peppers | 24,000 pounds |
| Potatoes | 32,000 pounds |
| Pumpkins | 56,000 pounds |
| Radishes | 32,000 pounds |
| New Zealand spinach | 16,000 pounds |
| Red peas | 4,800 pounds |
| Squash | 64,000 pounds |
| Tomatoes | 80,000 pounds |
| Turnips | 20,000 pounds |
| Watermelons | 160,000 pounds |
| Rice | 6,450 pounds |

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# Appendix C: Resources

AgriCultures Network: http://www.agriculturesnetwork.org/ ECHO: http://echonet.org/

"Managing Soil Fertility for Vegetable Production," Food & Fertilizer Technology Center for the Asian and Pacific Region: http://www.agnet.org/library.php?func=view&id=20110728123253&type_id=1

"Sustainable and Organic Production Techniques," Sustainable and Organic Agriculture Program, College of Tropical Agriculture and Human Resources: http://www.ctahr.hawaii.edu/sustainag

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