

Soils, crops and fertilizer use

A Field Manual for Development Workers

Prepared by

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About this manual

Soils, Crops, and Fertilizer Use is a field-oriented manual designed for use by generalists and ag specialists working with limited-resource farmers and gardeners. It's also well suited as a practical textbook for high school and university-level ag students.

This 4th edition is twice the size of the 3rd and is a completely new manual in many respects:

- It has been reorganized to enhance comprehension and readability.
- It is more extension-oriented with a stronger emphasis on limited-resource farmers.
- It promotes technical "networking" and grass-roots ag experimentation. A new appendix has been devoted to sources of technical support.
- It reflects the latest advances in technology, based on research and on-farm experience in many Third World countries.
- The chapter on organic fertilizers has been markedly revised and expanded to include in-depth coverage of composting, animal manures, manure tea, green manures, and cover crops.
- This edition uses the metric systems for two reasons. First, it's the official measurement system in many Third World countries. Second, most farm math calculations--especially fertilizer math--are far simpler and quicker using metrics.

How to Use This Manual

First of all, don't be intimidated by the manual's size, especially if you're a generalist with little or no ag background. Here are some suggestions for effectively accessing the manual's information:

- Begin by looking over the Table of Contents to see what subjects are covered and how the manual is organized.
- Note that the manual has a detailed index whose purpose is to improve information accessibility.
- Don't forget about the appendix section. It contains very useful information, yet is easily forgotten about unless you realize what's there.
- If you have little or no ag background, I urge you to read the manual from start to finish. If you're an agronomist or horticulturist, you may find it more useful to access information by using the index.

A Request for Feedback

I'd appreciate hearing your comments and suggestions concerning the manual. I'm also interested in learning about other soil management and fertilizer use practices that have proven successful for limited-resource farmers in your area.

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David Leonard

Part I: Soil physical management

Chapter 1: Down to earth - Some important soil basics

What is soil, anyway?

Most soils evolve slowly over centuries through the weathering of underlying rock and the decomposition of plants. Others are formed from deposits laid down by rivers and seas (alluvial soils) or by wind (loess soils).

Soils have 4 basic components:

- Mineral particles: sand, silt, and clay
- Organic matter
- Water
- Air

A sample of typical topsoil contains about 50 percent pore space filled with varying proportions of air and water, depending on the soil's current moisture content. The other 50 percent of the volume is made up of mineral particles (sand, silt, clay) and organic matter; most mineral soils range from 2-6 percent organic matter by weight in the topsoil. Organic soils like peats are formed in marshes, bogs, and swamps, and contain 30-100 percent organic matter.

Why do soils vary so much?

Your host country is likely to have dozens of different kinds of soils. In fact, even a small farm often has 2 or more types that vary markedly in their management problems and yield potential. The reason is that there are 6 soil-forming factors that determine the type of soil that develops in a particular spot:

- Climate: The higher the rainfall and temperature, the more rapid and complete the weathering process is. For example, the speed of chemical weathering reactions doubles for every 10°C (18°F) rise in temperature.
- Type of Parent Material: Soils are formed from a wide variety of parent material including many types of rock, vegetation, and animal life (e.g. the soil of Pacific atolls is formed largely

from coral). Rock varies a lot in its mineral makeup and other qualities. Some rocks like granite and sandstone are acid and tend to form more acidic soils than basic rocks like limestone and basalt.

- Vegetation: Soils formed under grassland differ from those formed under forest, although there are also variations within these 2 groups. For example, soils formed under pine trees tend to be more acidic than those formed under other tree species.
 - Topography exerts a big influence on erosion and drainage (the relative amounts of water and air in the soil pore space). In the tropics, red and yellow soils usually form on land with some slope since they need good drainage for their genesis. Black and grey soils are most common in depressions where drainage isn't as good.
 - Time: Soils change over time as they weather, a process that takes place over thousands of years. Soils vary in age a lot.
 - Farmer Management: Farming practices like land clearing, tillage, and cropping influence soil development by affecting erosion, pH, and organic matter, etc.
- Topsoil vs. subsoil

Dig down about 50 cm in most soils and you will have exposed 2 distinct layers: the topsoil and part of the subsoil. The topsoil is the uppermost layer and has these features:

- It's usually darker in color than the subsoil since it contains more organic matter from decaying plants and their roots.
 - It's more fertile than subsoil, due to having more organic matter and because fertilizers are usually added to the topsoil only.
 - It's usually looser and less compacted than the subsoil, mainly due to its higher organic matter content and to plowing (or hoeing).
 - The topsoil is usually about 15-25 cm thick. On cultivated soils, topsoil depth is about equal to tillage depth since this determines how deep organic matter and fertilizers are worked into the soil.
 - About 60-80% of the roots of most crops are found in the topsoil since it's a better environment for root growth than the subsoil (i.e. more fertile, less compact).
- The subsoil is located between the topsoil and the parent rock (or material) below. Aside from being lighter in color, less fertile, and more compact, it's usually more clayey; that's because downward water movement has transported some of the tiny clay particles from the topsoil into the subsoil.

The role of subsoil: It would seem that we could dismiss subsoil as not having much influence on crop growth. However, this isn't so for 2 good reasons:

- Subsoil is an important storehouse of moisture, especially since it's usually much thicker than the topsoil, and the moisture isn't lost as easily by evaporation. The higher clay content of subsoils makes for higher water holding capacity, too. This moisture reserve is very useful during dry spells, even though there are fewer roots in the subsoil. For example, it's estimated that half the moisture needed to grow a maize crop in the U.S. Corn Belt is already stored in the subsoil at planting time; rainfall during the crop's growth provides the rest but would fall far short by itself to produce good yields.
- Subsoil characteristics like clay content and compaction have a big influence on drainage (the ability to get rid of excess water).

Making Topsoil out of Subsoil: If little topsoil remains due to erosion, you can convert subsoil into productive topsoil. All it takes is hefty additions of organic matter like compost, manure, or green manure (see Chapter 8 on organic fertilizers) for a few years, but this isn't often feasible on large plots.

The mineral side of soil: Sand, silt, and clay

The mineral part of soil is composed of varying amounts of sand, silt, and clay. Their characteristics have a big influence on soil behavior and management needs.

Sand

- Of the 3 kinds of mineral particles, sand is the largest in size; about 50 sand particles laid side by side would equal 1 centimeter (125 per inch).
- Sand is mainly quartz (silicon dioxide) and contains few plant nutrients.
- Moderate amounts improve soil drainage, aeration, and tilth (workability).

Silt

- It consists mainly of ground up sand particles (quartz), which are often coated with clay.
- It contains few nutrients in itself except those that might be in the clay coating.
- Silt particles are too small to help improve drainage and aeration.

Clay

Clay particles are the smallest of the 3 (about 4000 of them laid side by side would equal 1 cm). Farmers know that clay has a big influence on soil behavior. High clay content usually makes for harder plowing, more compaction, and poorer drainage, but it does assure good water-holding capacity. Aside from this, clays have 3 other important features:

- **Source of plant nutrients:** Unlike sand and silt, clays are aluminum-silicate minerals that also have varying amounts of plant nutrients such as potassium, calcium, magnesium, and iron, etc. A good part of a soil's native fertility can come from its clay portion.
- **Clays have a negative charge:** This makes them act like tiny magnets to attract and hold those plant nutrients that have a positive (+) charge like potassium (K^+), calcium (Ca^{++}), magnesium (Mg^{++}), and the ammonium form of nitrogen (NH_4^+). This helps greatly to keep these nutrients from being carried downward beyond the root zone by rainfall or irrigation. (The term leaching is used to describe this type of loss.)
- **Tremendous surface area:** Each clay particle is really a laminated structure consisting of tiny plates. This lattice arrangement plus small particle size gives clays an amazing amount of surface area for attracting and holding positively-charged nutrients. In fact, one cubic centimeter of clay particles contains about 1-3 square meters of surface area.

All Clay isn't the Same

There are several different types of clay, and most soils contain at least two. Understanding some basics about clay types will help you interpret the soils in your work area. It's important to understand the difference between temperate clays and tropical clays and why both types are found in the tropics.

- **Temperate clays:** These are 2:1 silicate clays such as montmorillonite and illite that dominate the clay portion of most temperate zone soils but may also be found in the tropics. The 2:1 figure refers to the ratio of silicate to aluminum plates in a clay particle's laminated structure.

Soils with a good amount of these temperate clays are very sticky and plastic when wet; some kinds such as montmorillonite shrink and swell readily, forming large cracks upon drying out. They also have a relatively high negative charge (good for holding positively-charged nutrients).

- Tropical clays: These are 1:1 silicate clays, such as kaolinite, and hydrous oxide clays of iron and aluminum that often make up most of the clay portion of old, well drained soils in the tropics and subtropics, mainly in areas with at least 6 months of rainfall. These clays have lost lots of silicate due to centuries of weathering and leaching. Unlike the 2:1 clays, these “tropical” clays are much less sticky and plastic and are easier to work with, even when clay content is high. However, they usually have much less negative charge and lower natural fertility than temperate clays. Soils whose clay portion is largely “tropical” can usually be identified by their red or yellow colors.

Distinguishing “tropical” soils from “temperate” soils

Note that “tropical” clays don't necessarily make up the major portion of the clay in all soils of the tropics. In fact, temperate clays are surprisingly common, especially in younger soils or those formed under drier conditions or where drainage isn't good. A true tropical soil (one whose clays are mainly 1:1 or hydrous oxides) requires good drainage, centuries of weathering, and lots of rainfall and leaching to form. Likewise, not all clays in the temperate zone are 2:1 clays, especially in areas that may have once been tropical thousands of years ago. Some soils are mixes of both types.

Spotting “tropical” soils: A distinct red or yellow color, especially in the subsoil may be one indication. Such soils are unlikely to form in depressions but are found on gentle to steep slopes where drainage is good.

The extent of tropical soils in the tropics: Overall, true tropical soils account for about half the soils in the tropics and often exist side by side with “temperate” ones. They're fairly diverse themselves and are grouped into 2 broad categories based on the current USDA (U.S. Dept. of Agric.) soil classification system:

- Ultisols: Their clays are mainly 1:1 types, along with varying amounts of hydrous oxides of iron and aluminum, and their workability is usually good. They are moderately to very acidic and may have a high capacity to “tie up” added phosphorus, preventing its full use by plants.
- Oxisols: The most strongly weathered and leached of all soils. They're acidic and have high clay contents (mainly of hydrous oxides), but don't tend to be very sticky when wet. Like ultisols, they may tie up added phosphorus readily. One well known member of this order (group) are laterite soils whose subsoils are rich in a clayey material called plinthite that contains red mottles (blotches) and highly weathered oxides of iron and aluminum. Plinthite can harden irreversibly into ironstone (formerly called laterite) when exposed by erosion, as has occurred following deforestation. Note that true laterite soils at risk of ironstone formation are estimated to amount to less than 10% of all tropical soils.

Organic matter - A soil's best friend

Most cultivated soils contain about 2-4 percent organic matter by weight in the topsoil. Despite its small proportion, organic matter has a remarkably beneficial effect on soil behavior and crop yields, especially in the form of humus (partially decomposed organic matter that has become dark and crumbly; humus continues decomposing, but at a slower rate). Humus benefits the soil in many ways:

- It can greatly improve overall soil physical condition (filth), especially on clayey soils.
- Humus helps reduce soil erosion by wind and water, because it acts as a helpful “glue” to bind soil particles together into “crumbs” (called aggregates) that improve water intake rates

and lessen runoff. Such “crumbs” are also more resistant to being moved by wind or flowing water.

- It's an important storehouse and supplier of nutrients (especially nitrogen, phosphorus, and sulfur) which are slowly released for use by plant roots as organic matter decomposes. Estimates are that for each 1 percent organic matter in the topsoil, 600 kg/ha of maize can be produced without additional fertilizer.
- It increases the water-holding capacity of sandy soils (but not clay loams and clays whose water-holding capacity is already high).
- Humus has a high negative charge that helps prevent plus-charged nutrients from leaching. Per equal weight, humus has up to 30-40 times the negative charge of the lesser charged clays (i.e. tropical clays) and can account for the major part of a soil's nutrient-holding ability. In addition, negative charge improves a soil's buffering capacity (the ability to resist changes in pH; see Chapter 6).
- It helps prevent phosphorus and other nutrients from being “tied up” by the soil (i.e. being made unavailable to plants; see Chapter 6).
- Recent research has confirmed the observations of many organic gardeners and farmers that a high soil organic matter level can reduce the incidence of some soil-borne diseases and root-attacking nematodes. It also stimulates the growth of beneficial soil bacteria, fungi, and earthworms.

Organic Matter Does Wonders for Soil, BUT It's Hard to Maintain

Although forest or grassland soils have very healthy levels of organic matter (6-9 percent) in their untouched state, such levels can quickly decline once the land is cleared and put into crop production for several reasons:

- If the land is cleared by burning, much organic matter is destroyed.
- Plowing and hoeing aerate the soil, which stimulates soil microorganisms to speed up the breakdown of organic matter. Although this speeds up the release of nutrients from the organic matter, it can also result in a drastic decline in soil humus unless large, routine additions of organic matter are made.
- Forests and grasslands recycle huge amounts of organic matter back to the soil by leaf fall and root decay, but most crops (especially annual row crops like maize and peanuts) can't even come close to matching this. Row crops also expose the soil to higher temperatures which speed up the loss of organic matter. That's one reason why soil fertility and yields rapidly decline in 2-3 years under shifting cultivation (slash-and-burn agriculture).

Maintaining or Increasing Soil Organic Matter

Except on small plots, maintaining or increasing soil organic matter isn't likely to be easy for 2 reasons:

- It takes a huge amount organic matter to raise a soil's humus level by even one percentage point (i.e. from 3 percent to 4 percent). Each 1 percent of organic matter equals about 22,000 kg/ha (2.2 kg/m²).
- Soil organic matter is lost more quickly in the tropics, due to higher temperatures; breakdown occurs about 3 times as fast at 32°C (90°F) as at 16°C (61°F). In an experiment in New York, adding 56,000 kg/ha of stable manure per year for 25 years raised the topsoil's organic matter level by only 2 percentage points!

On the bright side: The good news is that you don't have to increase the percentage of organic matter in a soil in order to improve it. Why? Because when new additions of organic matter are made, the decomposition process releases compounds that provide many of the benefits listed above. You can probably raise organic matter levels on small plots, but on large areas it's more realistic and almost as beneficial to make routine additions of organic matter to keep the breakdown process active and help stabilize organic matter levels.

Some Suggestions for Encouraging a Healthy Turnover of Soil Organic Matter

- Return all crop residues to the soil except in the case of special insect and disease problems. It's OK if livestock feed on crop residues, as long as the manure is returned to the land (see Chapter 8).
- Don't prepare land by burning if there's a feasible alternative.
- Use compost, manure, and green manure crops wherever practical (these are covered in Chapter 8).
- Limit tillage operations like plowing, disking, and hoeing to the minimum needed for adequate seedbed preparation and weed control.
- Rotate low-residue crops like vegetables and cotton with higher-residue crops like maize and especially forage crops such as grasses and legumes.
- If liming is needed to correct excessive soil acidity, avoid excessive applications, because they accelerate the breakdown of organic matter by soil microbes. Avoid liming a soil to a pH above 6.5. (see Chapter 11.)

The role of soil microorganisms

The soil is a thriving biological laboratory, and a teaspoonful easily contains a billion microorganisms such as fungi and bacteria. Some cause plant diseases, but most are beneficial to agriculture. Some examples:

- Humus production: Many kinds of soil bacteria and fungi decompose organic matter into crumbly humus that does all those great things for the soil. The compounds produced by decomposition are also beneficial.
- Release of plant nutrients from organic matter: Most of the nitrogen, phosphorus, and sulfur in fresh plant residues is tied up in the unavailable organic form which plants can't use. Soil microbes change these tied-up nutrients into available inorganic (mineral) forms which plants can use.
- Mycorrhizae are a kind of mushroom fungi commonly found in most soils and infest the roots of many plants and trees. They cause no harm but actually enhance the host's uptake of plant nutrients, especially phosphorus (P); they also improve water uptake, lessen the toxicity of salinity or excess aluminum, and stimulate the growth of other beneficial microbes like rhizobia. They may even secrete growth-promoting hormones. In return, the plant provides the fungi with simple sugars for food. It's believed that mycorrhizae play a particularly important role in aiding the P uptake in some crops like sweetpotatoes and cassava (manioc) which seem to tolerate soils with low levels of available P. In the case of sterilized field or greenhouse soils that lack the fungi, considerable savings in phosphorus fertilizer have sometimes been obtained by inoculating them with a mycorrhizae culture, notably in the case of citrus nurseries. Topsoil from a disease-free, actively growing organic garden is likely to contain an especially good population of the fungi, and a few shovelfuls can be transferred to a new plot to encourage development. (However, mycorrhizae do not colonize the roots of beets, spinach,

chard, and brassica [crucifer] family plants such as cabbage, broccoli, radish, turnip, and pak choy.)

- Nitrogen fixation by rhizobia: Several kinds of bacteria “fix” (capture) nitrogen from the air and convert it to a form that plants can use. The most important type are rhizobia bacteria (of the genus *Rhizobium*) that live in small nodules on the roots of legumes. (Legumes are plants that produce their seed in pods such as beans, peas, and peanuts.) The rhizobia have a symbiotic (mutually beneficial) relationship with legumes. The bacteria live off sugars provided by the plant and supply their host with nitrogen. Some legumes such as cowpeas, peanuts, mungbeans, soybeans, and pasture legumes like clovers receive all the N they need from the rhizobia if the right strain is present.

- Other kinds of N fixation:

- Blue-green algae (cyanobacteria) inhabit flooded rice soils and fix N. Free-living types

(i.e. those requiring no host) fix modest amounts of N, and farmers in Egypt, India, and Burma purposely inoculate their rice paddies with these algae.

- The Azolla plant is a low-growing, aquatic fern which harbors a type of N-fixing, blue-green algae (*Anaerostipes azollae*) in its leaves. Azolla has been used as a green manure and also intercropped (grown in combination) with flooded rice for centuries in China and Viet Nam and can supply considerable N to the rice plants. (For more information on Azolla, refer to the section on rice in Chapter 10.)

- Azotobacter are free-living, N-fixing bacteria commonly found in unflooded soils of warm areas.

- Casuarinas are pine-like trees used for firewood, soil stabilization, and windbreaks in warm climates. Although not a legume, they do fix N, thanks to an association with an Actinomycete bacteria of the genus *Frankia*.

Chapter 2: Trouble-shooting soil physical problems

This chapter focuses on diagnosing and managing soil physical problems that affect productivity. Soil fertility problems are covered in PART II of this manual.

Getting to know the soils in your area

As explained in Chapter 1, it's difficult to make any useful generalizations about the soils of the tropics and subtropics. Soil-forming factors like climate, parent rock, time, topography, vegetation, and management interact in countless patterns. It's not unusual to find two or more soils on one small farm that vary markedly in texture, depth, slope, and other important features.

Here are the best ways of getting to know your area's soil's:

- Visit with farmers and walk through their fields with them. They're the ones most intimately involved with the land and can provide a wealth of useful information on local soils, their behavior, and productivity.
- Arrange for a soils field tour of your area with an agronomist or extension agent.
- Consult soil survey reports or other soil studies on your area. Soil specialists have devised several taxonomy systems to classify soils, first into orders and groups made up of hundreds of soils, progressing down to a very specific series consisting of several closely related soils that share many similar profile features. (A soil profile is a vertical slice of soil that includes the topsoil, subsoil, and some of the parent material below.) Of the several taxonomy systems, the one developed in the 1970's by the USDA in cooperation with other countries has become the

most widely used. The terms oxisol and ultisol used in Chapter 1 refer to two soil orders in this system that comprise hundreds of soils formed under tropical and subtropical conditions. (However, not all warm climate soils belong to these two groups, as explained in Chapter 1.)

NOTE: When reading a soil survey report, don't be intimidated by the technicalities and fancy terms. What's most important to farmers and extension workers is how a soil behaves when farmed - not what order or series it belongs to.

HOW TO EVALUATE A SOIL AND DIAGNOSE PHYSICAL PROBLEMS

Using a shovel and a homemade device to measure slope, it's fairly easy to evaluate the 6 major physical characteristics that determine a soil's behavior and management needs:

- TEXTURE
- DRAINAGE
- TILTH
- DEPTH
- WATER-HOLDING CAPACITY
- SLOPE

Let's cover them one at a time. But wait a minute, we haven't said anything about SOIL COLOR where does it fit in?

Soil color

A soil's color doesn't necessarily provide useful information on its characteristics and yield potential. For example, it's commonly believed that dark colors (especially black) indicate high organic matter content and, therefore, high natural fertility. This is often true in temperate regions like the prairie grasslands of the Great Plains (USA) where there is a direct relationship between soil color and humus content - the blacker the soil, the more humus it contains and the more fertile the soil. However, this correlation isn't universally valid, because soil humus in warmer regions has a more brownish coloration. Also, parent rock itself can make a soil black. In fact, many black soils in the tropics and elsewhere owe their color not to high humus content but to a reaction of the calcium in their limestone parent material with only a small amount of humus.

Distinct red and yellow colors usually indicate very old and weathered soils likely to be acidic and low in natural fertility; their clay portion usually contains a high amount of "tropical"-type clays (hydrrous oxides of iron and aluminum, and 1:1 clays like kaolinite) that are lower in negative charge but less sticky when wet than soils high in "temperate" type clays (see Chapter 1).

Subsoil color is also a valuable indicator of how well drained a soil is as will be explained in the section on drainage in this chapter. Now, on to the 6 mayor "vital signs" of soil physical health.

Soil texture

Texture refers to the relative proportions of sand, silt, and clay in a soil (see Figure 2-1). Note that humus content technically has nothing to do with texture. A soil's texture has a big influence on its productivity and management needs, because it affects filth, waterholding capacity, drainage, erosion potential, and soil fertility.

Texture usually varies with depth: As explained in Chapter 1, the subsoil is usually more clayey than the topsoil.

There are 3 broad soil textural classes: Sandy, Loamy, and Clayey; they are further subdivided as shown in Table 2-1.

TABLE 2-1 TEXTURAL CLASSES OF SOIL

SANDY SOILS* LOAMY SOILS* CLAYEY SOILS*

Sands (CT) Sandy Loams (CT) Sandy clays (FT)

Loamy sands (CT) Fine sandy loam (CT) Silty clays (FT)

Very fine sandy loam (MT) Clays (FT)

Loam (MT)

Silt loam (MT)

Silt (MT)

Clay loam (FT)

Sandy clay loam (FT)

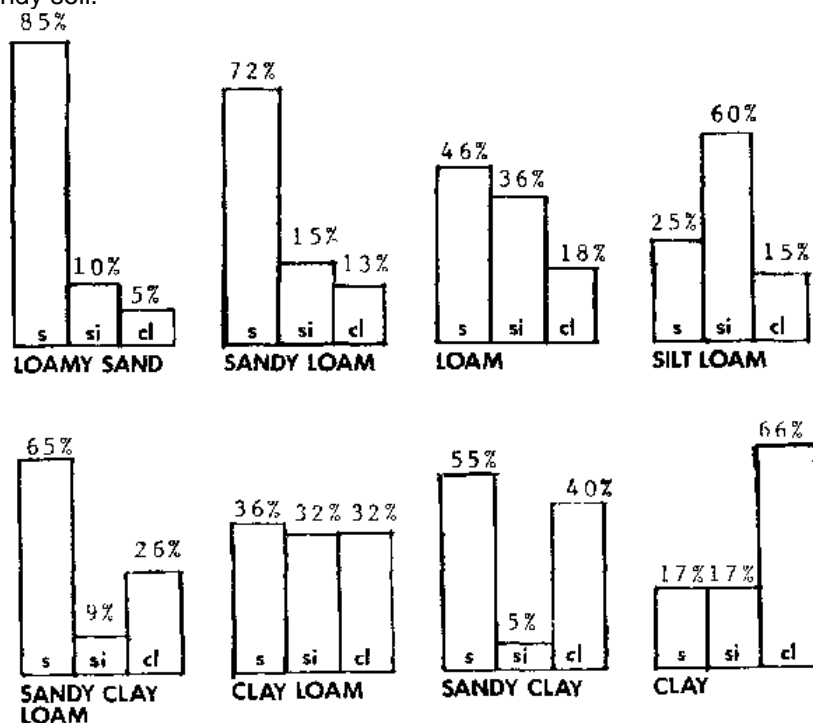
Silty clay loam (FT)

* "Coarse-textured" (CT), "medium-textured" (MT), and "fine-textured" (FT) are other adjectives used to describe soil texture. Coarse-textured and fine-textured soils are also referred to as "light" and "heavy" soils respectively.

Checking Out Soil Texture in the Field

For farming and extension work, you don't need to determine the exact percentages of sand, silt, and clay. In fact, just being able to place a soil in one of the 3 broad textural classes (i.e. sands, loams, clays) may be sufficient. However, it's usually helpful to be more specific, and, with the help of Table 2-2, you shouldn't find this difficult. A good way to begin is to first determine whether the soil is sandy, clayey, or loamy, and then fine tune your diagnosis.

FIGURE 2-1: The bar graphs show the relative percentages of sand, silt, and clay according to soil texture. Each category above actually has a range in its percentage of sand, silt, and clay. For example, sandy clay soils may range from about 35-65% sand, 0-15% silt, and 37-55% clay. Likewise, clay soils may range from 45-100% clay, 0-38% silt, and 0-45% sand. Note that soil can have as little as 37% clay (as in the case of a sandy clay soil) and still fall in the clayey textural class. That's because it takes relatively little clay to make a soil exhibit clayey characteristics. The reverse is true with sand; it takes about 75% sand content before a soil starts to behave like a sandy soil.



(s = sand, si = silt, cl = clay)

THE PROS AND CONS OF SANDY, LOAMY, AND CLAYEY SOILS

Sandy Soils

Advantages

- Easily tilled.
- Resistant to compaction caused by animal, foot, or machinery traffic.
- Absorb water readily.
- Usually well drained unless the water table is close to the surface as can happen in low areas and depressions.

TABLE 2-2: Determining Soil Texture in the Field

SOIL TYPE Visual Appearance Squeeze Test Feel When Moist*

SAND Loose, single-grained When dry and squeezed, it falls apart when released.
If wet, it crumbles readily when touched.

Gritty

SANDY LOAM Loose When dry and squeezed, it falls apart easily when released. If wet, it forms a cast that crumbles without careful handling.

Gritty

LOAM Few clods When dry and squeezed, it forms a cast that needs careful handling. If wet, the cast can be freely handled without breaking.

A bit gritty but slightly putty-like (plastic)

SILT LOAM Cloddy, but clods are easily broken

Same as above. Only slightly plastic or gritty; feels like talcum powder.

CLAY LOAM Cloddy and lumpy when dry.

When wet and squeezed, it forms a cast that holds together under heavy handling.

Plastic; forms a ribbon when rubbed between forefinger and thumb, but it breaks easily.

CLAY Hard lumps or clods when dry.

The wet cast can be tossed and caught without breaking.

Very plastic and sticky; forms a ribbon easily.

* If dry, add water drop by drop, and knead the soil to break down all clumps until the soil feels like moist putty. If too wet, add dry soil to soak up the water.

Disadvantages of Sandy Soils

- Low water-holding capacity (about half that of clay loams and clays); tend to dry out quickly.
- More leaching of plant nutrients due to low negative charge and more downward movement of water (because of lower water holding capacity).
- Tend to be lower in natural fertility (but not always) due to greater leaching and low content of nutrient-bearing clay.

Loamy Soils

The term "loam" is a bit confusing, because it conveys nothing about sand, silt, and clay content. A loam isn't simply an equal mixture of the three, either. As shown in Figure 2-1, loam soil contains about 45% sand, 40% silt, and 15% clay. That's because it takes much more sand than clay to influence soil behavior. Ideally, a loam combines all the advantages of both sandy and clayey soils without having any of their bad points. A clay loam has enough additional clay to exhibit some of the negative features of clay soils, but not enough to be classified as a clay. Likewise, a sandy clay has enough extra sand to have some moderate problems with water-holding capacity and excessive leaching, but not to the extent of a true sandy soil.

Clayey Soils

Advantages

- Good water-holding capacity (about twice that of sands).

- Less leaching of plant nutrients, due to higher negative charge and less downward water movement because of higher water-holding capacity). (Remember, however, that “tropical” clays can have a very low negative charge.)
- They tend to be higher in natural fertility than sandy soils, but not always, especially those whose clay minerals are mainly “tropical” types.

Disadvantages of Clayey Soils

- Harder to till, not only in terms of power required, but also regarding ideal moisture range for tillage. If plowed when too wet, they compact and stick. If worked when too dry they're overly hard and cloddy.

- More prone to poor drainage, due to slower downward movement of water. (Not a problem on a slope).
- More prone to soil compaction by animal, foot, or machinery traffic.
- Their slow water intake rate encourages excessive runoff on slopes.
- Soils high in clay (or silt) tend to crust over upon drying which can inhibit seedling emergence. Beware of Overgeneralizing!

Don't interpret the above comparisons of sandy, loamy, and clayey soils too rigidly. Many clayey soils aren't poorly drained or high in natural fertility. Likewise, all sandy soils aren't low in natural fertility. Of the 3 groups, clayey soils are probably the most variable in their traits.

Is Natural Fertility Important?: Probably not as much as it once was, since most farmers have access to chemical or organic fertilizers. Fertility is usually much easier to improve than physical problems like poor drainage, insufficient depth, or excessive clay; however, farmers without enough organic fertilizer may not have funds or credit for purchasing chemical fertilizer.

HOW TO IMPROVE SANDY AND CLAYEY SOILS

NOTE: Refer also to the section on clayey soils in Chapter 4.

- Add organic matter to either: Compost, manure, and green manure crops will greatly benefit these soils (as well as loams). Aside from adding nutrients, they loosen up clayey soils and bind together sandy soils. They also improve the water holding capacity of sands and increase their negative charge. Organics like rice hulls' millet hulls, cottonseed hulls, and peanut hulls (shells) don't add many nutrients but are valuable for loosening up clayey soils. Organic soil conditioners are covered in detail in Chapter 8.
- Try mulching: Covering the soil with a layer of straw, dried grass, or leaves, etc. will help reduce water evaporation losses from sandy soils. Mulching clayey soils will eventually add organic matter and encourage earthworms, both of which will have a loosening effect.
- Reduce animal, foot, and machinery traffic over clayey soil, especially when wet, to help minimize compaction.
- In poorly drained clay soils, plant crops on raised beds or ridges to prevent the plants from getting "wet feet". (Raised beds are covered in Chapter 4).
- Planting on a flat bed or sunken bed is often recommended for sandy soils (and sometimes others) in dry areas or where dry spells are common. (See Chapter 4).
- Add sand to clay or clay to sand: From what you've read, you should be able to interpret this poem:
"Clay to sand is like a bird in hand
Sand to clay is like throwing money away"

As the poem implies, you'd have to add a lot more sand to a clayey soil than clay to a sandy soil to modify its behavior. The third line of the jingle might be, "A little bit of clay goes a long way". Check the soil texture bar graphs (Fig. 2-1) again and see how much sand content is needed for a soil to rank as a sandy soil compared to clay for a clayey soil. Whether you try to add sand to clay or vice-versa, this remedy is only likely to be practical on very small plots, especially when adding sand.

Soil tilth

Tilth refers to a soil's physical condition. A soil in good tilth is easily worked, crumbly, and readily takes in water when dry. A soil in poor tilth is hard to work, overly cloddy or loose, and absorbs water slowly when dry.

What influences tilth?: Texture, organic matter, and moisture content all play a role.

A soil's tilth isn't static: It can vary markedly with changes in soil moisture content, especially on some clayey soils which can be worked only within a very narrow moisture range without being too hard or too sticky.

How to Maintain or Improve Soil Tilth

- Improving tilth by adding sand to clay is only practical on smaller plots and will still require considerable labor.
- Routine additions of organic matter to the soil are very helpful.
- Land drainage or the use of raised beds or ridges may help alleviate excessive moisture that's causing poor tilth.
- Time tillage operations: Under favorable moisture conditions, plowing and hoeing may improve tilth by breaking up clods and loosening hard ground. But when done when too wet or too dry, tillage can leave the soil worse off than before.
- Don't overdo tillage: Stirring and shearing the soil aerates it which stimulates fungi and bacteria to accelerate the breakdown of valuable humus. Tillage may loosen the topsoil but it often compacts the subsoil, especially when done with tractor or animal-drawn equipment on wet, clayey soils.
- Choose crops carefully: Some crops like cotton, peanuts, tobacco, and vegetables require frequent traffic down the rows for spraying and cultivating. Soil tilth will suffer and compaction increase unless these crops are rotated with others like grains and forage crops that require less field traffic and return more organic matter to the soil.

Soil water-holding capacity

How Soils Hold Water

- About half a soil's volume is pore space which is occupied by varying amounts of air and water, depending how wet the soil is.
- Water is held in the pore spaces in the form of films adhering to the soil particles.
- The smaller pores in the soil are called micropores the larger ones are macropores. Macropores don't hold water well, because the water films become too thick to adhere well to the surrounding soil particles.

All Soil Water isn't Available to Plants

Soils hold water very much like a sponge, so we'll use this analogy to explain some basic soil water principles. Get a sponge and a pail of water, and follow along:

- Dip the sponge in the water and then hold it over the pail. Some of the water is draining from the sponge, even though you're not squeezing it. This water is being lost from the macropore spaces in the sponge where the films become too thick to be held against the pull of gravity. It's the same way with soil after a rain or irrigation. Water begins to move out of the macropores

downward through the soil. This is drainage water. It moves down until it reaches the water table (where water ponds) or runs into drier soil where it becomes held in the micropores.

- Available vs. unavailable water: The water that remains in the sponge after natural drainage is all held in the micropores. It's the same with the soil. A soil at this stage is said to be at field capacity (micropores full). Now squeeze the sponge. At first, it's easy to extract water, but then it becomes harder and harder. Again, it's the same with the soil. Only about half the water held at field capacity is actually available to plant roots. As the soil dries out, the water films become thinner and are held increasingly tightly to the soil particles, making it harder for roots to get water. When the permanent wilting point is reached, plants will remain wilted (and may die) unless water is added, even though the soil is far from completely dry. This remaining, unusable water is called unavailable water.

The Difference Between Water-Holding Capacity and Drainage

At first, it might seem contradictory that some soils can have both good water-holding capacity and good drainage, but these characteristics are compatible. That's because drainage takes place only from the macropores, and water-holding capacity resides in the micropores. The films of micropore water are resistant to being drained away by gravity. It's the macropores that allow a soil to retain enough air for the roots as long as drainage isn't impeded.

How Soil Texture and Organic Matter Influence Water-Holding Capacity

Soil texture has the biggest influence on water-holding capacity. As shown by Table 2-3, clays and clay loams have about twice the water-holding ability of sandy soils. That's because, in terms of pore space, clayey soils have a much larger proportion of waterholding micropores compared to sands. Surprisingly, they also have more total pore space, too, which is why dry clay usually weighs less than dry sand, given equal volume.

TABLE 2-3: The Effect of Soil Texture on Water-Holding Capacity

Liters of Available Water Held Per 30 cm	
Depth of Soil Per Square Meter*	
Inches of Available	
Water Held per Foot	
(30 cm) of Soil	
Sands	6.3-18.9 liters 0.25-0.75"
Loamy sands	18.9-31.2 liters 0.75-1.25"
Fine sandy loams	37.5-43.5 liters 1.50-1.75"
Clay loams	43.5-62.5 liters 1.75-2.5"
Clays	50.0-62.5 liters 2.00-2.5"

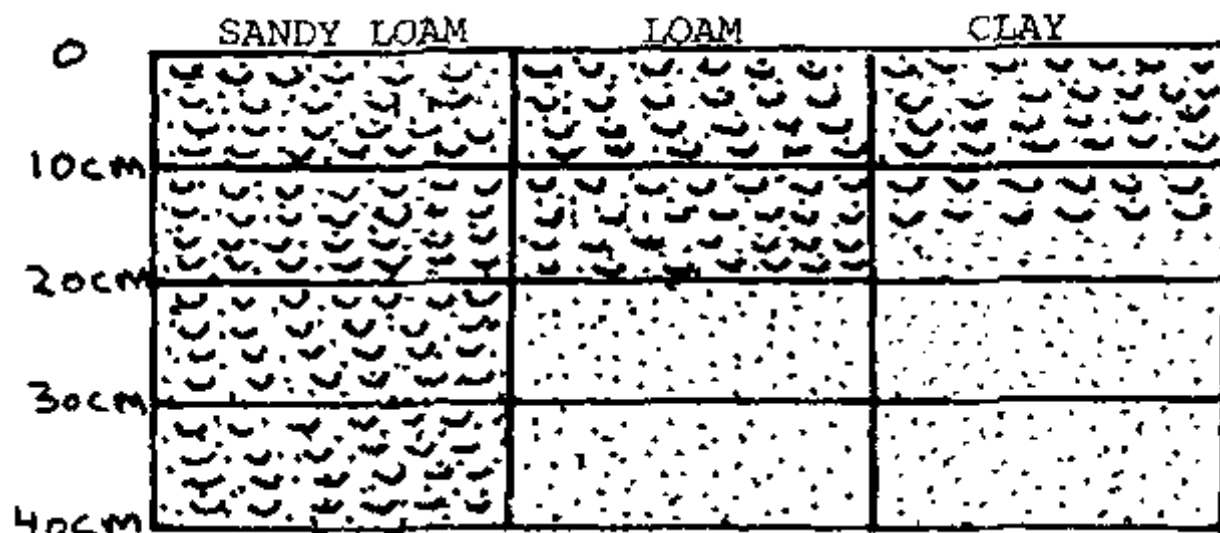
*These figures are based on the soil being at field capacity (i.e. micropores filled, macropores empty).

Humus can help in some cases: Humus will help increase the water-holding capacity of sandy soils but won't help much on clayier soils that already have good water-holding ability.

Water-Holding Capacity and Water Penetration

Figure 2-2 illustrates the important concept that sandy soils are more prone to leaching losses than clayey soils because of their lower water-holding capacity. If lettuce plants with roots 30 cm deep were being grown on the sandy loam and the clay soil in Fig. 2-2, the clay soil could receive almost twice as much water per application as the sandy loam without having leaching losses. It would also require watering only about half as often as the sand. Total amount of water needed per week would be the same for both soils, however.

FIGURE 2-2: Depth to which 3 cm of water (30 liters per sq. meter) will refill a dry soil (in this case, at the permanent wilting point) to field capacity.



Soil drainage

Drainage refers to the soil's ability to get rid of excess water (water in the macropores) through downward movement by gravity. It is affected by topography, texture, filth, depth, and the presence of pans (compacted or cemented zones). Nearly all major crops need fairly good drainage so that their roots can obtain enough oxygen; some exceptions are rice and most varieties of taro (*Colocasia esculenta*).

Poorly drained soils adversely affect crop yields in several ways:

- Roots lack adequate oxygen, since the macropores are largely filled with water.
- Soil-borne fungal and bacterial diseases are encouraged.
- Nitrate nitrogen (a nutrient) is subject to loss by a process called denitrification (see Chapter 6).
- Manganese and iron may become soluble enough to injure plant roots.

Although clayey soils are more likely to have drainage problems, they also may occur on sandy soils in cases where the water table is close to the soil surface. (The water table is the upper surface of the ground water, below which the soil is completely saturated with water.)

How to Spot Drainage Problems

You and farmers can easily spot areas of poor drainage in a field. Here's what to look for:

- **Topography:** Poor drainage is most likely to occur on level fields or in low spots where water tends to collect after a rain or irrigation. Soils with even a gentle slope seldom have drainage problems but are likely to have the opposite problem of excessive water runoff.
- **Presence of Hardpans or Claypans:** A hardpan is a hardened, cemented layer a few centimeters thick, usually located in the lower topsoil or upper subsoil. It remains hard even when wet, and restricts drainage and root growth. A claypan is a thicker, dense clayey layer in the subsoil which will soften somewhat when wet. It still impedes drainage and root growth. Dig a pit to check for such pans.
- **Crop Appearance:** Crops growing in poorly drained areas will be stunted and yellow compared to surrounding portions. Beware, though, that other conditions such as nitrogen deficiency and disease can produce these symptoms. Suspect poor drainage only when

stunting and yellowing are associated with low spots or areas of standing water.

- Standing Water: Any area where water ponds for a day or two after rainfall or irrigation is likely to be poorly drained.

- Subsoil Color: Red, reddish brown, or yellow subsoil colors indicate very good drainage.

That's because the presence of sufficient air allows the soil's iron and manganese to remain in the oxidized form, indicated by bright colors. Dull greys and blues indicate a reduced state (little oxygen) which means poor drainage. Some soils in wet-dry climates have subsoils with alternate streaks of bright and dull colors. This color pattern is called mottling and indicates fluctuations in soil drainage (i.e. good in the dry season, poor in the wet season) caused by the seasonal variation in the height of the water table.

How to Test Soil for Poor Drainage

- The hole test: Dig a hole 60-90 cm deep and fill it with water; allow it to drain, and refill it again. In a well drained soil, the water level should fall by 2-3 cm an hour and disappear in 24 hours. However, if poor drainage is being caused by a hardpan or claypan, this test won't be valid, as you will have overcome the problem by digging through them.

- Checking for a high water table: Poor drainage in low spots is often caused by a high water table. Ideally, the water table should be at least 100 cm below the soil surface, at least during the cropping season. When digging, you can easily tell when the water table has been reached, since water will begin to pond in the hole.

NOTE: In some cases, a high water table can actually benefit crop growth by supplying water to the roots during long dry spells by upward capillary movement (as long as it's not high enough to affect drainage in the major root zone area). However, there's always a risk of poor drainage in wet years on such land.

Dealing with Drainage Problems

First, determine what is causing the drainage problem before deciding which of the methods below will be effective.

- Seedbed styles for poorly drained areas: Growing crops on raised beds or ridges can alleviate drainage problems that aren't serious. See Chapter 4.
 - Breaking up pans: This can be done with digging hoes and picks or with tractor-drawn subsoilers (narrow shanks that penetrate 40-50 cm deep). Hardpans can sometimes be permanently fractured and loosened. Claypans, however, tend to reconsolidate after being loosened, especially since they're usually moist and don't tend to fracture. On small plots, the best way to permanently loosen a claypan is by double-digging the soil and adding an organic soil conditioner to the pan area. (Double-digging is covered in Chapter 4.)
 - Drainage ditches for surface water: These are shallow, wide ditches that follow the natural depressions in the field to conduct water away. Make sure the outlet is satisfactory, so one farmer's drainage problems won't be passed on to another.
 - Drainage ditches for subsurface water: Shallow ditches remove only surface water. To remove excess subsurface water, deeper and more numerous ditches can be used. They will "pull" (attract) this excess water from the soil between them. These ditches are usually spaced about 15-45 meters apart, depending on the soil (the closer spacings for clayey soils) and are dug 30-60 cm deep. Top widths range from about 2-5 meters and bottom widths about 1.5-2 meters. Ditches with V-shaped sides permit the passage of farm machinery. Of course, the ditches must be designed to convey the water off the field and eventually into a natural drainage way such as a stream.
 - Drainage tile or Plastic pipe: Drain pipe can be rayed 80-100 cm underground to drain saturated subsoils and conduct the water off the field. Short sections (30-40 cm long) of 10-12 cm diameter clay pipe can be laid end to end in a trench and covered with straw, building paper, or earth to facilitate water entry and retard plugging. Flexible, perforated plastic pipe may also be available for this purpose in your country. The pipe or tile are laid at a slight slope (about 25-50 cm per 100 meters of length) and lead to an outlet such as a ditch or canal. The distance between the tile or pipe lines varies from about 10-20 meters on clayey soils to 30-90 meters on sandy soils. If the land has a natural drainage way, running such an underground drainage line along this path can speed up the removal of water from these areas of accumulation.
 - Land leveling will fill in depressions and lower high spots, although the high spots may end up losing lots of topsoil. Animal-drawn scrapers can be fabricated locally.
- Seedboxes have special drainage problems: See Chapter 4.

Soil depth

Soil depth refers to the depth of the topsoil plus subsoil and can be easily determined with a shovel. Soils can be classified as being deep or shallow as follows:

Depth (Topsoil + Subsoil)

Deep soils 90 cm +

Moderately deep 50-90 cm

Shallow 25-50 cm

Very Shallow Less than 25 cm

Actual vs. Usable Depth: There's often a big difference between actual depth and usable depth, because the factors listed below can also limit root penetration:

- Excessive subsoil compaction.
- Hardpans and claypans (explained in the drainage section).
- Poor drainage.
- Excessive subsoil acidity (very low pH).
- Potential rooting depth of the crop itself; some are naturally much deeper-rooted than others. (See Table 5-1 in Chapter 5 on water management.)
- Overly shallow watering can restrict depth of roots, since they will not grow into dry soil.

The Value of Deep Rooting

Deep rooting isn't necessarily essential for good crop yields. Some shallow soils can produce excellent yields if well managed. However, there are benefits to encouraging deep rooting:

- Better drought tolerance.
- Better nutrient uptake since the roots explore more soil.
- In irrigated crops, deeper rooting allows more water to be applied per application and more time between waterings. This can be very helpful in areas where farmers use furrow irrigation and receive water from the main ditch on an erratic schedule.

How to Encourage Deeper Rooting

- Use raised beds or ridges since they actually increase soil depth and provide a double layer of topsoil. However, they're not suited to dry conditions, because they dry out too fast.
- Double-digging will help encourage root growth into previously uninviting subsoil.
- Avoid overly shallow watering; this is most likely to occur on clayey soils because of their high water-holding capacity.
- Fertilizer use will stimulate deeper rooting.

Soil slope

A field's slope has a marked influence on the amount of water runoff and soil erosion caused by flowing water. Slope is usually measured in terms of percent. A 10 percent slope has 10 meters vertical drop per 100 meters horizontal distance (or 10 ft. per 100 ft.). A 100 percent slope equals 45 degrees. Soil conservation measures become necessary on land with as little slope as 1-2 percent.

You can measure slope with a homemade device. This is covered in Chapter 3 on soil conservation.

Chapter 3: Basic soil conservation practices

There are few areas in the world where soil erosion by water or wind hasn't taken its toll, either on the farm or in the surrounding environment. This is especially true in much of the Third World, where harsh climatic conditions, ranging from torrential rainfall to drought and damaging seasonal winds, have combined with unsound land use practices to accelerate erosion problems. On-farm erosion results in soil loss, yield reduction, and even abandonment of the land. In the surrounding environment, erosion is both a cause and effect of deforestation and desertification.

This chapter provides a basic introduction to conservation methods for combatting soil erosion on small farms.

Rainfall erosion

The effects of rainfall erosion

On those sloping soils where soil conservation methods aren't used to combat rainfall erosion, farmland and yields will be adversely affected for several reasons:

- Soil depth decreases due to loss of topsoil.
 - Soil fertility declines. Rainfall erosion carries away mainly the smallest soil particles -the nutrient-laden humus and clay particles that contain most of a soil's fertility. Studies have shown that eroded material found at the bottom of a slope contains 2-5 times more plant nutrients than what's left behind.
 - Soil filth deteriorates due to the loss of topsoil and humus.
 - Soil moisture decreases due to increased water runoff and less infiltration into the soil.
- In addition, the surrounding environment is harmed:
- Floods increase due to more water runoff into rivers and streams. This often causes off-farm erosion as well.
 - Canals, rivers, and dams can become silted up as eroded soil accumulates.
- The mechanics of soil erosion by rainfall

It helps to know your enemy. Rainfall erosion is caused by the "dynamic duo " of raindrop splash and surface flow on sloping soils. Raindrops act much like tiny hammer blows that do several nasty things, given their overwhelming numbers:

- They compact the soil, reducing water infiltration and increasing runoff.
 - They break down clods into their component particles which are then more vulnerable to being carried away by moving water.
 - They keep soil particles in suspension, which greatly aids their transport and also exerts a scouring action against the soil surface, detaching even more particles.
- Raindrops hitting a level field aren't a problem, because soil is moved equally in all directions. However, when rainfall strikes sloping soils (and it takes surprisingly little slope, as we'll see), serious erosion can occur due to 2 types of surface flow:

- Laminar flow is a uniform flow of water most common on gentle slopes and causes sheet erosion.
 - Channelized flow is more common on steeper slopes where water tends to collect and move downhill in channels. At first, this produces small furrows only a few centimeters deep called rills. If allowed to continue, however, gulleys 30-100 cm deep are the inevitable result.
- The Magnitude of Rainfall Erosion Losses: An unprotected field with only a 4-5 percent slope (4-5 meters drop per 100 meters horizontal distance or about a 2° incline) can easily lose 100 metric tons per hectare of soil a year, which equals about 1 centimeter of depth.

Factors that influence rainfall erosion

Human interference, slope, rainfall, soil condition, and ground cover are the main factors affecting the amount of rainfall erosion that occurs.

Human Interference

Although erosion often occurs in the untouched natural environment, several types of human interference have led to accelerated rainfall erosion:

- Forest fires and grassland burning.
- Logging and firewood cutting.
- Farming on unprotected slopes: Even the practice of shifting cultivation (see Chapter 8), which can be ecologically sound under low population pressure, is now a prime cause of erosion in countries such as the Philippines where pressure on the land has forced an ever-decreasing length in the rejuvenating vegetative fallow period.
- Overcultivation of farmland due to land pressure and excessive production of cash crops like peanuts and cotton. Such crops are likely to encourage erosion, because they're slow to produce protective ground cover and leave relatively little post-harvest residue for maintaining soil organic matter.
- Overgrazing by livestock on slopes is a main cause of the serious rainfall erosion damage in countries such as Lesotho.

Slope

Both the steepness of slope and its length are important:

- Doubling the steepness of slope increases erosion losses by 150 percent, due to increased water flow speed. The soil-carrying ability of water is proportional to the 6th power of its velocity. (For example, doubling the speed of flowing water increases its capacity to transport soil by 64-fold.)
- Doubling the length of slope increases soil losses by 50 percent by allowing water to build up more volume and speed.

Measuring slope: Two methods are described in the upcoming section on conservation practices.

Rainfall

Both the amount and intensity of rainfall are important, especially the latter. An annual rainfall of 250 mm concentrated over just 3 months can cause more erosion than 2000 mm spread out over 10-12 months. In fact, rainfall erosion is very common in semi-arid areas such as the African

Sahel whose short rainy season consists largely of brief, high-intensity showers; in addition, such regions usually lack the protective vegetative cover of wetter areas.

Soil Condition

The condition of the soil has a big effect on erosion losses:

- A healthy level of humus (at least 3-4 percent by weight) acts as a beneficial “glue” that binds together soil particles to produce a crumb-like structure. These miniature clods (called aggregates) are heavy enough to avoid being moved downslope by water and also resist being broken apart by raindrop splash.
- Soils in good filth (physical condition) allow water to penetrate much more readily, which lessens the amount of downslope runoff.
- Some very old and weathered tropical soils with a high proportion of hydrous oxide clays (see Chapter 1) have a natural crumb-like structure unrelated to humus content, which makes them less erosion-prone, much like soils with good organic matter levels.

TABLE 3-1

Effect of vegetative cover on soil erosion losses on a 40% slope under 2000 mm annual rainfall in Puerto Rico.

Treatment Soil Loss per Year (metric tons per hectare)

Bare, exposed soil 286.7

Crop rotation of maize, sweet potatoes, etc. 38.1

Sugarcane 17.2

Grass pasture 2.7

Amount of Ground Cover

Any type of ground cover, such as mulch, crops, or natural vegetation, is very effective at reducing raindrop splash and surface flow velocity. Plant roots also help hold soil together. The value of plant cover depends a lot on the crop, its spacing, and the amount and rate of leaf growth. As shown by Table 3-1, nearly any type of vegetative cover is far superior to soil.

Techniques for combatting rainfall erosion

This section is designed to give you some basic entry-level skills in soil conservation and to lay the groundwork for further investigation and intelligent discussion with farmers and conservation specialists.

As with many other farming practices, soil conservation is a location-specific endeavor, meaning that methods must be adapted to the particular soil, climate, and farming practices. If you plan to promote soil conservation in your work area, you'll want to do several things first:

- Seek assistance from the local ag extension service and also the forestry service which usually is engaged in soil conservation too. Whenever possible, plug yourself into any ongoing programs rather than working on your own.
- Visit farms where successful conservation measures are in effect. Bring along farmers who are considering conservation.
- Confer with farmers likely to benefit from conservation practices to sound out their ideas, needs, and expectations.
- Read up on the subject; some helpful references are listed in Appendix H.

Motivating Farmers to Adopt Soil Conservation Practices

It's a fact -soil conservation also means moisture conservation: It's not always easy to convince farmers anywhere in the world to undertake soil conservation practices. Some methods, such as terracing and contour ditching, require much labor, and the immediate benefits may appear vague. Approaching soil conservation solely from the standpoint of saving soil isn't likely to motivate farmers enough. However, an important immediate benefit of any soil-saving method is increased moisture retention which usually results in higher yields. Unprotected slopes are usually droughty due to high water runoff and reduced infiltration. Such a yield boost may, in itself, provide enough motivation for farmers to adopt soil conservation practices; this has been the case in El Salvador for many small farmers who plant maize, sorghum, and beans on steep slopes.

A Summary of Some Common Rainfall Erosion Control Methods

Soil conservation is a specialty too broad to be fully covered here. Instead, we'll first briefly summarize the common techniques listed below and then cover a few in more detail (those marked with an asterisk). You'll also learn how to determine slope and lay out contour lines - two essential initial steps in most conservation methods.

Common Soil Conservation Methods

- Mulching* (discussed in Chapter 8)
- Contour plowing and planting
- Contour strip cropping*
- Contour ditching and banking*
- Rock walls
- Various types of terracing*
- Reversion to permanent pasture or forest

It's helpful to remember that any practice that reduces raindrop splash or surface flow will help combat rainfall erosion.

Mulching: Even a small amount of mulch cover can markedly cut erosion losses. One study on a moderate slope showed that soil losses were cut 75 percent by spreading straw over the soil surface at a rate equal to 850 kg/hectare (85 grams per sq. meter). In some cases, erosion scars on steep slopes can be stabilized by covering the area with brush, working from the bottom up, and anchoring it with stakes. Soil runoff from above gradually covers the brush, forming an area where plant cover can be established.

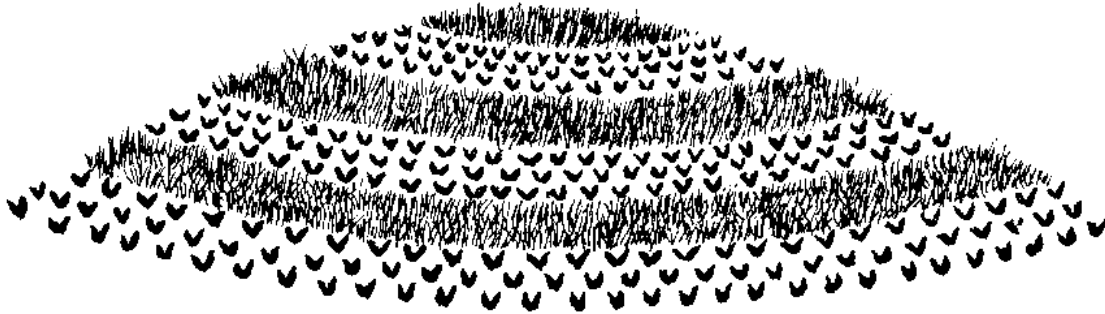
Contour Plowing and Planting: In this method, plowing is done following the contour of the slope

(i.e. at right angles to the direction of the slope) instead of straight up and down it. The crop rows also run along the contour. When used as the sole conservation measure, it may prove adequate on slopes up to 8 percent and not more than 100 meters long, depending on soil, cropping, and rainfall factors. At best, this practice cuts erosion losses about 50 percent.

FIGURE 3-1: A field that has been plowed and planted on the contour.



FIGURE 3-2: Contour stripcropping.



Contour Stripcropping: This method carries contour plowing and planting a step further, and some versions may be suited to slopes as high as 40-50 percent. The main features are:

- Strips of close-sown or otherwise protective crops (i.e. leucaena, grass, sisal, pineapples, small grains) are alternated between strips of row crops such as maize and beans, all following the contour.
- The strips' downslope widths vary with soil conditions but range from about 25-40 meters wide for 2-7 percent slopes to 4 meters wide for 40-50 percent slopes.
- The close-sown strips slow down water runoff speed (which builds up on the row-crop strips), increase water infiltration, and reduce runoff water volume.

Later in this chapter, we'll cover a contour strip-cropping technique called S.A.L.T. (Sloping Agricultural Land Technology) that's proven successful in the Philippines.

Contour Ditch and Barrier System: It can be reasonably effective on slopes as high as 45 percent (about 24 degrees). The system's main features are:

- It combines contour plowing/planting with the placement of small ditches that follow the contour and that are spaced at intervals down the slope.
 - The soil excavated during ditch building is placed along the downhill side of the ditches to prevent water from overflowing them.
 - A 30-50 cm wide live barrier of dense grass (elephant, guinea, etc.), pineapple, or sisal is planted along the upper bank of the ditches to hold the soil together and to trap any soil that might be carried downslope into the ditches by runoff water.
 - Row crops can be planted on the contour between the ditches which are spaced anywhere from 4-20 meters apart, depending on conditions.
 - If upright crops like maize, sorghum, and bush beans have soil thrown into the crop row (called "hilling up") for weed control and support, this will also act as a further barrier to downslope water movement.
 - The ditches are designed to have a gentle 0.5% slope so that they can slowly conduct excess water off the field.
 - The ditches lead into a grass- or rock-lined waterway which carries the water to the bottom of the slope without causing gulleying. (NOTE: A protected waterway is critical, or the field may suffer serious erosion, no matter how well made the rest of the system is).
 - Where the subsoil is clayey and holds water well, catchment basins can be dug (either inside the ditches or at their ends) to collect and save water for using on the crops during dry spells.
- The contour ditch and bank system has been used with success in Central America, the Caribbean, and other areas. We'll cover it in more detail later on in the chapter.

FIGURE 3-3: The contour ditch and bank system.



Rock Walls: On rocky, hilly land in El Salvador, many farmers have controlled erosion successfully using low, drystone (uncemented rock) walls built at intervals along the contour. Here are the basic features:

- The walls help check erosion by trapping downward-moving soil and slowing the speed of runoff water. (Remember that the soil-carrying ability of moving water is proportional to the 6th power of its velocity!)
- For stability, rock walls shouldn't exceed a height of 60 cm above the soil surface and should have a tapering profile (about 40 cm thick at the top to about 60 cm at the base). In addition, the base should begin about 30 cm below ground.
- Over time, rock walls and other barrier systems will often result in a natural terracing and reduction in slope as soil carried downslope by runoff piles up in front of the walls.

Terraces: There are several different types of terraces and all involve reshaping of the land to a greater extent than the other methods above. Below are 3 types of terraces and their features. All can be built with lots of hand labor, but the first 2 can also be made with animal-or tractor-drawn plows and scrapers (V-drags).

- Broad channel terraces are designed mainly to intercept and then divert excess water safely from the field and are usually most suited for wetter regions and slopes not exceeding 15-20 percent. As with the contour ditch and barrier system (see above), a grass or rock-lined waterway is essential for safely conveying excess water off the field without erosion.
- Ridge terraces are designed to intercept and retain excess water by spreading it out over wide areas of the field between the ridges. Unlike channel terraces, they're better suited to drier regions on soils that absorb water readily. Note that ridge terraces are best used on gentle slopes (not much over 3 percent), since the area over which the water is spread can be large without having to make an unreasonably high ridge.
- Bench (step) terraces can be used on slopes of 20-50 percent and convert the land into a series of "steps" separated by nearly vertical risers lined with rocks or vegetation for protection. Though labor requirements are very high, well constructed bench terraces give excellent erosion control and allow a wide variety of crops to be grown. We'll cover bench terraces in more detail later on in this chapter.

Reversion to Permanent Pasture or Forest: On steep, badly eroded land, this may be the sole feasible alternative, but will succeed only where overgrazing, unrestricted tree cutting, or burning can be prevented.

Some Useful Skills for Rainfall Erosion Control

Now that we've summarized the main control methods, we'll cover some of the useful skills and practices in more detail:

- How to measure soil slope with homemade devices.
 - How to lay out contour lines using simple, homemade devices.
 - How to lay out and construct a contour ditch and bank system.
 - The basics of the S.A.L.T. (Sloping Agric. Land Technology) strip cropping method being used in the Philippines.
 - How to lay out and build a contour ditch and bank system.
 - Some guidelines for bench terrace construction.
- Be sure to check the local ag extension and forestry service for further information, as well as the bibliography in Appendix H.

HOW TO MEASURE SOIL SLOPE

One of the first steps in undertaking soil conservation practices on a farm is to measure soil slope, since it's a main factor influencing erosion susceptibility as well as the type of conservation methods best suited.

Soil Slope Basics

Soil slope is almost always measured in percent rather than degrees, and you'll see why this is more convenient as we move along. Land with a 4 percent slope has a vertical drop of 4 meters

for every 100 meters of horizontal distance. A slope of 100 percent is not a vertical cliff but equal to 45 degrees (1 meter vertical drop per 1 meter horizontal distance).

FIGURE 3-4: Illustration of 4%, 20%, and 100% slope.

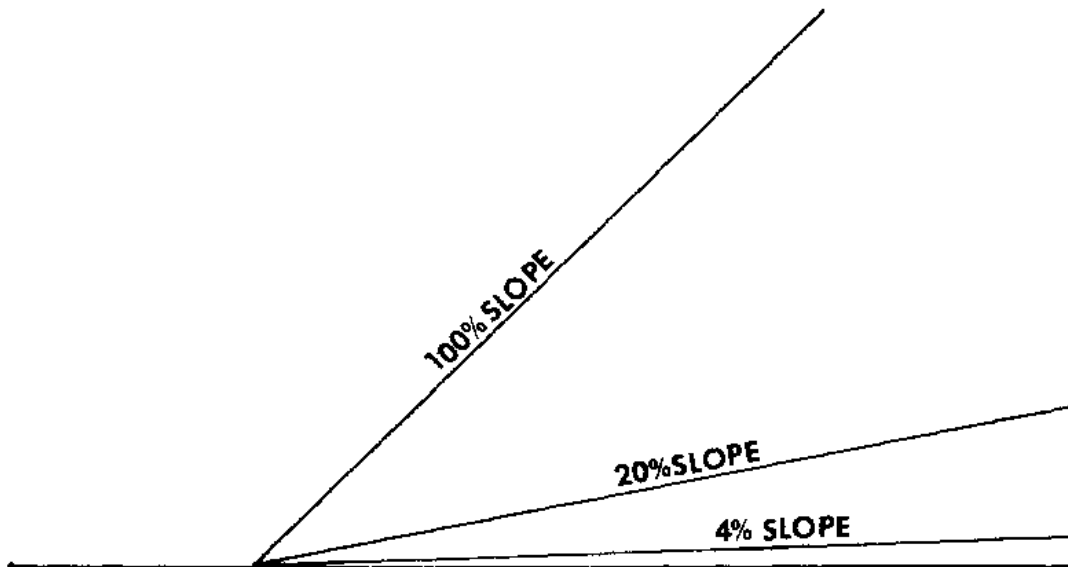


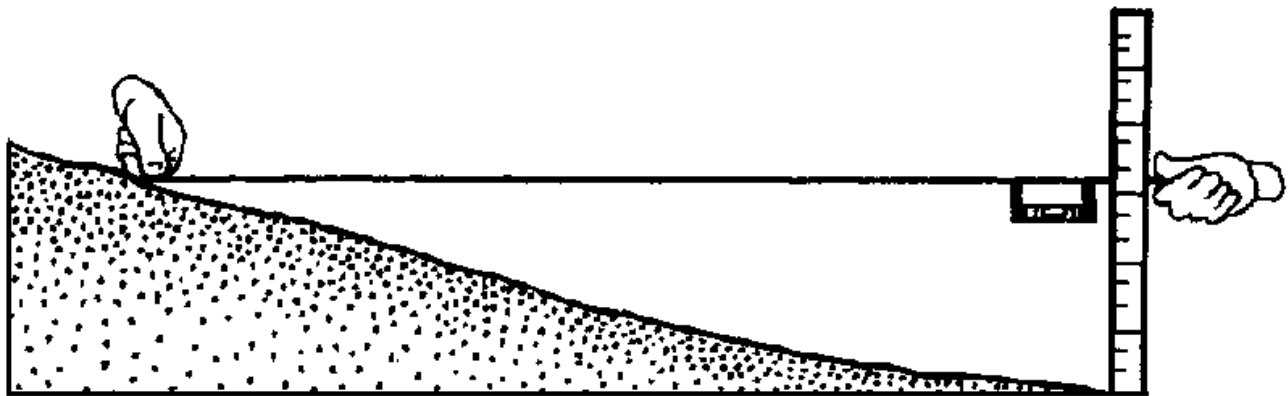
FIGURE 3-5: A carpenter's (or mason's) string level (actual size)



How to Use a String Level to Measure Soil Slope

Perhaps you can borrow an inclinometer (Abney level) from your extension or forestry service. However, farmers can easily measure soil slope accurately using a simple device called a string level ("nivel de pita" in Spanish) that's used by masons and carpenters worldwide (Figs. 3-5 and 3-6). It should be available at any hardware store for about \$1-\$3 (U.S.).

FIGURE 3-6: Measuring soil slope with a string level.



Items Needed: String level

Length of string or twine 4-10 meters long; nylon twine works best.

Measuring tape or homemade ruler about 1-1.5 meters long with centimeter markings.

Two people (one will do).

STEP 1: Hang the string level at one end of a length of string. Ten meters (1000 cm) is a good length for moderate slopes and makes the math work a snap. As explained below, a 5 meter length is more practical for steeper slopes.

STEP 2: Choose a fairly uniform section of the slope. Hold that end of the string that has the level near it, and have your partner grasp the other end. Your partner should now proceed directly upslope (not laterally) until the string is taut.

STEP 3: Have your partner anchor her end of the string to the ground with her fingers; if alone, use a small stake.

STEP 4: Now raise your end of the string slowly upwards until the string level gives a level reading (the bubble will be centered in the middle right between the two lines). For accuracy, be sure to clear away any vegetation or clods along the string's path that may interfere with it.

STEP 5: Now measure the vertical distance between the end of the level string and the ground. This will give you the slope's vertical drop over 10 meters. (NOTE: Use a shorter length of string on steeper slopes or you'll have trouble raising your end high enough. Also, if the slope varies over the field, take and record readings at several representative locations.

STEP 6: Calculate the percentage slope using this simple formula:

Examples: 1. Suppose you measure a vertical drop of 60 cm on a 10 meter string. The slope would be 6 percent:

$$60 \text{ cm}/1000 \text{ cm} = 6/100 = 6\%$$

2. Suppose you use a 4 meter length of string on a steeper slope and measure a vertical drop of 140 cm. The slope would be 35 percent:

$$140 \text{ cm}/400 \text{ cm} = 35/100 = 35\%$$

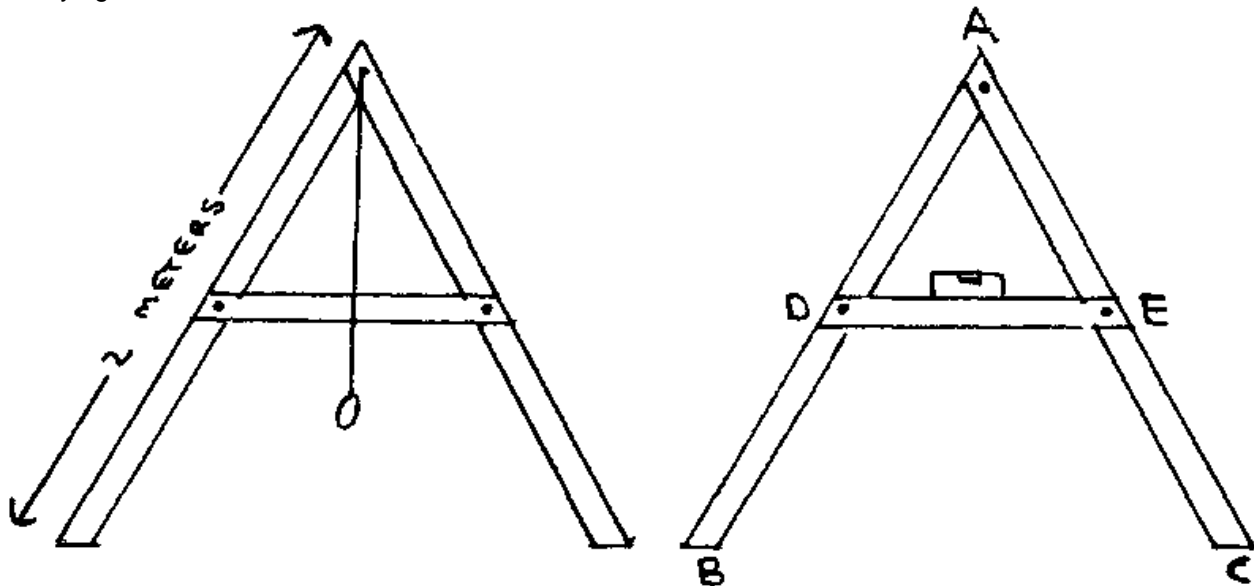
HOW TO LAY OUT CONTOUR LINES

A Homemade Device for Laying out Contour Lines

Nearly all rainfall erosion control methods, including strip cropping, the ditch and bank system, and terracing, are done on the contour (i.e. across the slope). Laying out contour lines that mark the path for plowing, crop rows, and barriers is an important skill to master. You can show farmers how to do this easily and accurately using a device called an A-frame.

NOTE: A water level is another simple device for laying out contour lines and can also be used to measure the percentage of slope. Its main component is a water-filled length of clear plastic tubing about 5-15 meters long. It functions on the principle that the water level at each end of the tube denotes 2 points of equal elevation. However, since the water level costs more, this manual is describing the A-frame in detail. The local ag extension or forestry office may have water levels and can show you how to make and use them.

FIGURE 3-7: Plumb-line A-frame (left) and carpenter's level A-frame (right) used for laying out contour lines.



Making and Calibrating an A-frame

Items Needed: Two wood or bamboo poles about 2 meters long

One wood or bamboo pole about 100-120 cm long

A hammer and nails

String

A small carpenter's level (about 20-40 cm long) or a homemade plumb-bob and 1 meter of

string.

STEP 1: Build the A-frame as in the drawing above. Poles cut from brush or bamboo will do fine. Twine or nails can be used to secure the 3 pieces together. The crossarm is placed about 1/2-2/3 of the way up and should be mounted reasonably level. Make the feet somewhat pointed at the bottom.

STEP 2: You can use either a plumb-line or a carpenter's level on the A-frame for determining contour lines.

A plumb-line will be accurate enough when the wind is still but isn't reliable in any type of breeze.

a. Mounting the plumb-line: It should be hung from a nail (centered in the juncture) where the 2 legs meet. Hang a small weight like a fishing sinker or piece of metal scrap at the end as a plumb-bob.

b. Mounting a carpenter's level: In this case, be sure to use a very straight and smooth piece of wood for the crossarm. Tie the carpenter's level firmly to the crossarm with twine as shown above. NOTE: You can try using a small string level instead.

STEP 3: Now you can calibrate the A-frame to make it accurate as follows:

a. Calibrating a plumb-line A-frame

- To find the level mark on the crossarm, choose a fairly level spot of ground. Now pound 2 pointed stakes about 25-30 cm long halfway into the ground at a distance equal to the spread of the A-frame's legs.
- Stand the A-frame on the stakes and make a pencil mark where the plumb-line comes to rest. Now reverse the legs and make a second mark. The true level mark will be located exactly halfway between. Mark it with a pencil.
- To double-check your calibration, adjust the A-frame's position by gradually pounding one of the stakes further into the ground until the plumb-line comes to rest on the true level mark. Now reverse the A-frame's legs again; if the plumb-line returns to rest on the level mark, the A-frame is properly calibrated.

b. Calibrating a carpenter's level A-frame

- In this case, you want the carpenter's level to read level (i.e. bubble centered between the 2 lines) when the A-frame's legs are sitting on 2 points that are perfectly horizontal to each other. The easiest approach is to make sure that the following measurements in Fig. 3-7 are equal to each other: $AB = AC$, $DB = EC$; also make sure that the piece of wood used for the crossarm is perfectly straight.
- To test the A-frame, set its legs on 2 stakes that have been hammered into the ground (as in a. above). If the bubble rests to the right of center, gradually pound the right stake into the ground until the bubble is centered between the lines. If the bubble rests to the left, do the same with the left stake.
- As a final check, rotate the A-frame 180 degrees so that the position of the legs is exactly reversed. The bubble should indicate level again. If not, either the distances DB and EC aren't equal or perhaps the carpenter's level is defective. (When placed on a perfectly horizontal surface, an accurate level will produce no change in the bubble's centered position when rotated 180 degrees.)

Laying Out Contour Lines with an A-frame

Contour lines run at right angles to the slope (across the slope). All points on the line are at the same elevation. Here's how to lay out a contour line with an A-frame:

Items needed: A-frame, stakes, hammer (or rock)

STEP 1: Pound a stake into the ground at the starting point for a contour line (i.e. the start of a proposed contour ditch or a strip of a closely-sown crop that will run across the field).

STEP 2: Stand the A-frame in the soil with one leg directly at the base (not on top) of the first stake and the other leg pointing in the approximate direction the contour line will run.

STEP 3: Now keep the leg at the base of the first stake in place and use it as a pivot point to move the other leg up and down the slope until you get a level reading with the plumb-line (or carpenter's level). Pound in a second stake where this leg comes to rest.

STEP 4: Now shift the A-frame one stake over so that the leg that rested at the base of the first stake now rests at the second stake. As in Step 3, move the other leg uphill or downhill until you get a level reading, and pound in another stake.

STEP 5: Keep repeating Step 4 until you reach the end of the field.

STEP 6: Even out irregularities: Even on uniform slopes, small rises and depressions in the terrain may cause some stakes to be out of line. You can take out any abrupt deviations by slightly altering some of the stakes' positions as shown in Figure 3-9.

FIGURE 3-8: Laying out a contour line across a sloping field using an A-frame.



FIGURE 3-9: Adjusting stake positions to even out a contour line.



NOTE: Be sure to recalibrate the A-frame each time it's used after storage.

HOW TO LAY OUT A CONTOUR DITCH AND BARRIER SYSTEM

This system was summarized a few pages ago. Here's how to lay out and construct the ditches and barriers:

STEP 1: The protective waterway must be established first. In a heavy rain, the contour ditches will conduct large volumes of water off the field. This means they must empty into a protected waterway so that the excess water can reach the bottom of the slope without causing erosion. If possible, consult with a soil conservation specialist as to the best location and type of waterway. Some guidelines:

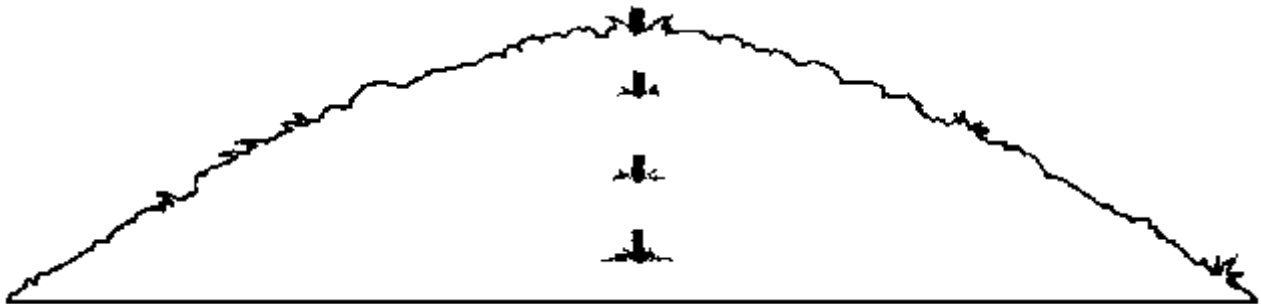
- Given the potential volume of runoff, waterways on either side of the field may be needed.
- Check over the area just beyond where ditches will end and look for natural depressions that could serve as a waterway path.
- Allow for sufficient waterway width (5-10 meters, depending on the area of the field).
- Erosion protection: The waterway area must be either lined with rocks or planted to a dense, low-growing grass such as bermuda grass, kikuyu (*Pennisetum clandestinum*), carpet grass (*Axonopus compressus*), bahia grass (*Paspalum notatum*), star grass (*Cynodon plectostachyus*), and molasses grass (*Melinis minutiflora*). The vegetative cover must be well established before the ditches are built and the rains come. This takes at least several months and may not be feasible during the dry season. Establishing the vegetation during the previous wet season may be the best solution. The same is true for the vegetative barriers needed along the uphill bank of the ditches (Step 7).
- Before planting the cover, check the soil pH, and apply lime, if needed. Apply fertilizer to encourage rapid growth. (Refer to the section on pastures in Chapter 10.)
- Keep livestock out of the waterway, and don't use it as a roadway.

STEP 2: Measure the field's slope. The spacing of the ditches depends on the field's slope (the

steeper it is, the closer they need to be spaced). First measure the slope and then refer to the table in Appendix C to find the correct horizontal interval.

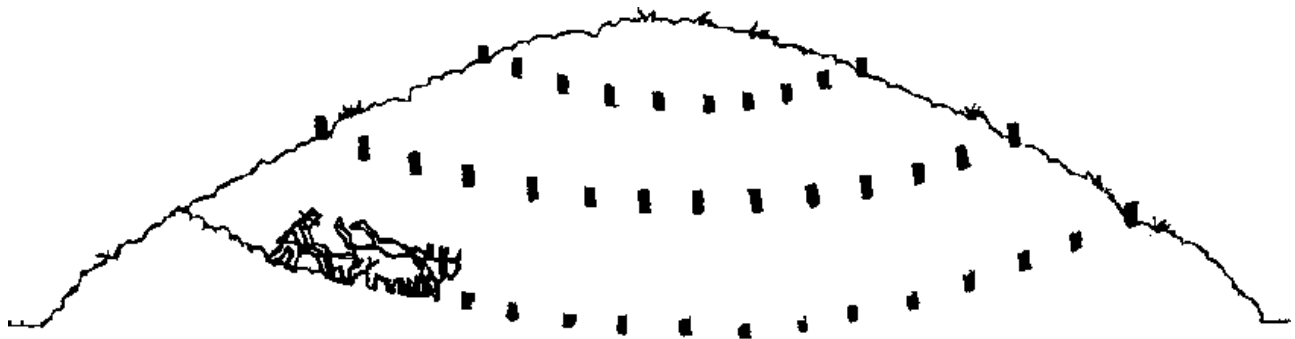
STEP 3: Determine the ditches' locations. Begin at the top of the field. Suppose the field's slope is 25 percent. The table gives a horizontal interval of about 7 meters. This means the first ditch should be 7 meters directly downslope from the top. The succeeding ditches will also be located at 7 meter intervals. Proceed downslope and place a stake at each of these intervals. These are master stakes which serve as guides for laying out the contour lines along which the ditches will run (see Fig. 3-10). The stakes can be placed down one side of the field or down the middle. If the slope noticeably changes as move downhill, you'll need to measure these variations and adjust the ditch spacings accordingly (use the table in Appendix C).

FIGURE 3-10: Master stakes indicating the locations of the contour ditches.



STEP 4: Use the A-frame to mark out the ditch paths with stakes. You'll need lots of stakes since they'll be placed at intervals equal to the A-frame's leg span. Begin at the master stake for either the top bottom ditch and lay out the contour path for each ditch following the guidelines given in the last section.

FIGURE 3-11: Hillside field with 3 staked-out contour lines representing ditch paths. The ox-drawn plow is doing the initial loosening of the soil along the ditch path.



NOTE: Need for a ditch grade: In order to prevent excess water from overflowing the ditches, they should be laid out to have a 0.5% slope (i.e. a 50 cm drop every 100 meters of length) so that excess water can be safely conducted off the field to a grass -or rock-lined waterway where it can flow to the bottom without causing erosion. Don't exceed a 0.5% slope or the water's speed may erode the ditches. You'll learn how to "build in" a 0.5% slope into an A-frame shortly.

NOTE: Don't worry if the slope changes as you move across the field laying out the lines. You'll see that the lines are "self-correcting" in that they'll move apart as the slope decreases and move closer as it increases. That's because, being contour lines, the vertical interval between them

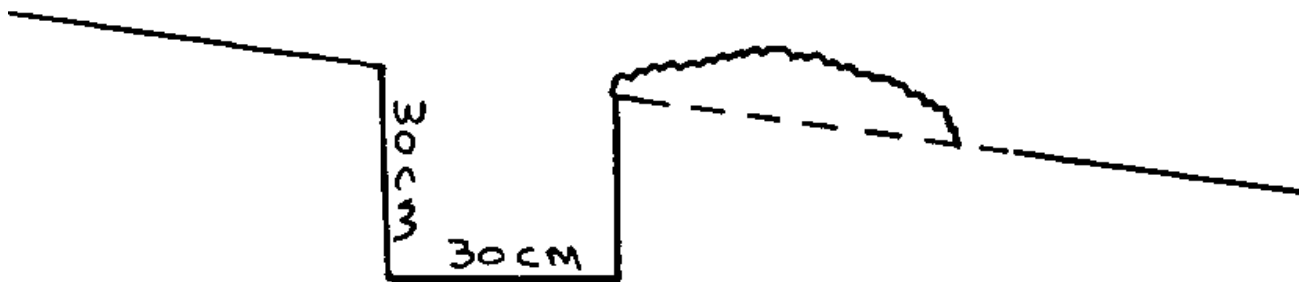
won't change even when the slope changes (although the horizontal distance will)

STEP 5: Even out any irregularities in the stake lines as shown in Figure 3-9.

STEP 6: Dig the ditches. If available, have an animal- or tractor-drawn plow loosen up and dig out soil right along the line of stakes (see Fig. 3-11). (It's OK for the plow to knock out the stakes, since the furrow it makes will indicate the ditch path.) If using a moldboard (turning plow), run it so the soil is thrown to the downhill side of the ditch, as that's where the soil barrier will be built.

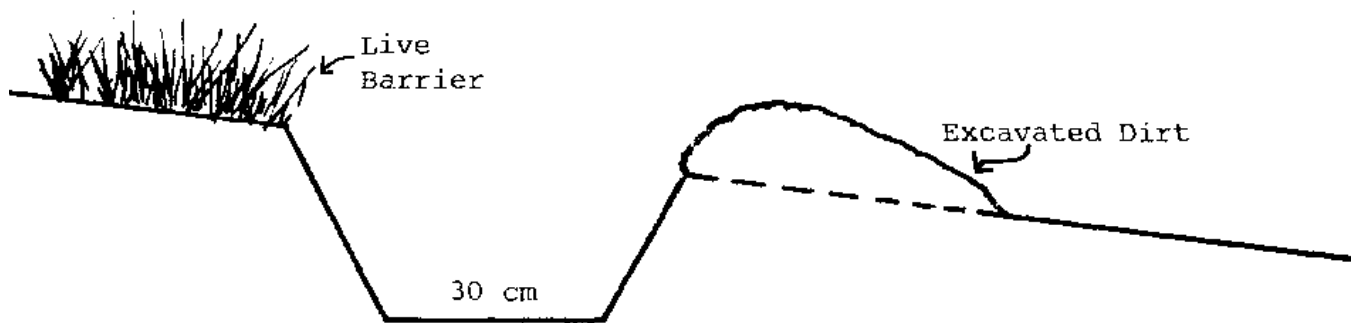
Continue digging out the ditch with shovels, piling the excavated soil along the downhill bank. Begin by making the ditch about 30 cm wide and 30 cm deep as in Fig. 3-12.

FIGURE 3-12: Initial shape of contour ditch; note that excavated soil is placed on the downhill side.



To help prevent the ditches from caving in, taper the sides like so:

FIGURE 3-13: Completed contour ditch with sloping sides; note live barrier of grass on upper side to prevent soil from being carried into the ditch.



STEP 7: Make a vegetative or rock barrier on the uphill bank of the ditches. This will prevent soil from being carried into the ditches and should be about 30-40 cm wide. Some possible plants: elephant grass, jaragua grass, kikuyu grass, pineapple, sisal. Check locally to find out what's best suited. Some grasses like kikuyu spread rapidly but may begin overrunning the field and become weeds.

STEP 8: Make dikes in the ditches if appropriate. In some cases, partial dikes can be built in the ditches every 5 meters or so to slow down water flow and encourage infiltration. This will depend on the soil and rainfall conditions.

Using the system: Once installed, the ditches also serve as the master contour lines for the plow and the crop rows to follow. Where subsoils are clayey and hold water well, catchment basins can

be dug at intervals along the ditches or at their ends for collecting water for use during dry spells.

How to Build a 0.5% Slope into an A-frame

This is necessary in order to lay out the ditches with a gentle slope so excess water is encouraged to move off the field rather than overflowing the ditches. Here's how to build in a 0.5% slope into an A-frame:

For A-frame with Plumb-line

STEP 1: Calibrate the A-frame and place it on a level surface so that the plumb-line indicates level.

STEP 2: Measure the leg span in cm and multiply this by 0.5%.

Example: 140 cm leg span X 0.5% = 0.7 cm or 7 mm

STEP 3: Now raise one leg up a distance equal to the figure derived in Step 2, and make a mark where the plumb-line comes to rest. Now draw a short arrow from the mark so that it points toward the direction of the unraised leg.

STEP 4: Place the A-frame back on level ground, and repeat Step 3 using the other leg.

Using the adjusted A-frame: Use it just as you would to lay out normal level contour lines. However, in this case, don't use the level mark but one of the 0.5 percent marks you made in Steps 3 and 4. The arrow next to the mark you use indicates the downhill direction the ditch will run. When laying out a ditch line across a field, always use the same mark from start to finish, and don't rotate the A-frame 180 degrees. Otherwise, the ditch may change direction from uphill to downhill. However, if you're using 2 waterways on either side of the field, half the ditches (or half of each ditch) should lead to one side and the rest to the other side.

For A-frame with Carpenter's Level

In this case, there are 2 ways of building in a 0.5% slope:

METHOD 1: Make one of the A-frame's legs shorter than the other by an amount equal to 0.5% of the leg span. Draw an arrow on the cross arm pointing toward the longer leg. The arrow indicates the downhill direction the ditch will run when the ditch line is laid out with the bubble centered on carpenter's level. When laying out the ditch line, don't rotate the A-frame 180 degrees or the ditch will change its gradual slope from downhill to uphill.

METHOD 2: Calibrate the A-frame and place it on a level surface so the bubble is centered. Now raise up one leg of the A-frame an amount equal to 0.5 percent of the leg span. Adjust the carpenter's level so that it reads level even though the A-frame isn't. Now draw an arrow on the crossarm pointing toward the unraised leg. When laying out ditches with a 0.5 percent slope, the arrow indicates the downhill direction of the ditch when the bubble is centered. Don't rotate the A-frame as you proceed across the field or the ditch's direction will reverse.

THE S.A.L.T. SYSTEM FOR CONTROLLING RAINFALL EROSION

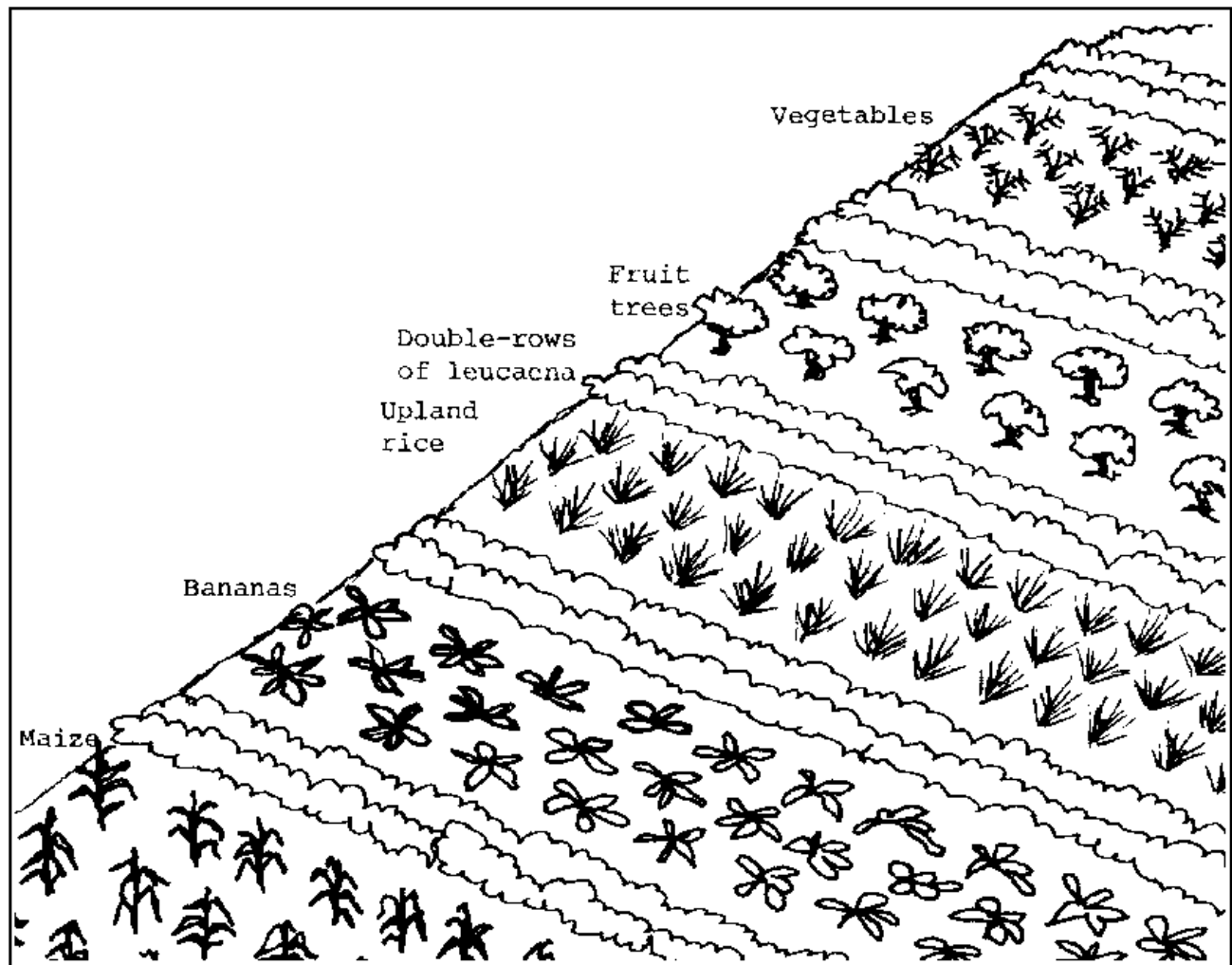
The S.A.L.T. system (Sloping Agricultural Land Technology) was briefly described earlier in this chapter under strip-cropping methods. It was developed by the Mindanao Baptist Rural Life Center in Davao del Sur, Philippines in 1979 and has become increasingly popular in that country since then. Although it can be effective on very steep slopes, it's best suited to regions with a long rainy season which allows the growing of soil-stabilizing perennial crops like cacao, banana, and

pineapple without irrigation. It incorporates the use of a leguminous tree/shrub called leucaena or ipil-ipil (*Leucaena leucocephala*), although other perennial legumes could be substituted. Here are the main features and practices of S.A.L.T:

- Contour lines are laid out across the slope at intervals of 4-6 meters, depending on steepness and soil conditions.
- A one meter-wide strip along each contour line is plowed up following the marker stakes. Two planting rows 50 cm apart are prepared, and leucaena seeds are sown 2-5 cm apart. Though slow-growing at first, the leucaena will form a thick, erosion-resistant hedgerow in 4-6 months and may reach 5-6 meters in a year. Aside from erosion protection, its leaves are used for mulching and fertilizer (being a legume, they're high in N), and the plants provide firewood, poles, and animal feed (leaves and pods).

- While the leucaena is becoming established, the land is best left in its natural vegetation instead of being plowed. However, tree crops like citrus and banana can be planted and weeded by working only the immediate area around the plant, thus not inviting erosion.
 - Once the leucaena is established, other strips between these perennial crops can be plowed and planted to more erosion susceptible annuals like maize and vegetables.
 - The leucaena is cut once a month down to 1 meter height and the leaves are placed around the base of the crops for fertilizer and mulch.
 - Natural terrace formation: Barriers are formed by piling rocks, stalks, leaves, and branches at the base of the leucaena rows. Over the years, any soil carried downslope will collect at the barriers, and a natural terracing will take place.
- NOTE: Large blocks of leucaena aren't recommended for steep, unstable slopes, unless they are pruned regularly to allow sunlight to reach the soil so that undergrowth will develop.

FIGURE 3-14: S.A.L.T. system of soil conservation for hill, land.



Some Limitations of leucaena

Like most "wonder crops", leucaena has its strengths and weaknesses. On the one hand, it's fast-growing (although not initially), has a deep taproot, fixes nitrogen, and regrows readily after cutting. It can be used for erosion control, reforestation, fuel, poles, forage, mulch, and fertilizer. However, it does poorly on very acid soils (below pH 5.0), is frost-sensitive, and may not grow well above 500 meters elevation, even in the tropics. Its slow initial growth makes it prone to weeds

and insects during the early weeks. Leucaena leaves contain excessive mimosine (an amino acid) which can be toxic to non-ruminants like pigs, chickens, and horses if fed at anything but low levels. (However, some low-mimosine strains of leucaena have been identified.)

In 1985, the Philippines, Tonga, and Fiji reported serious outbreaks of psyllid insects (jumping plant lice of the genus *Heteropsylla*) in leucaena plantings. These small sucking insects have several natural predators in Mexico and the Caribbean where leucaena is native. It may be possible to introduce these predators to the affected areas.

Where to find out more about S.A.L.T.: Mindanao Baptist Rural Life Center, Kinuskusan, Bansalan, Davao del Sur, PHILIPPINES.

SOME GUIDELINES FOR BENCH (STEP) TERRACES

Bench terraces were briefly described earlier in this chapter and can be used on land with slopes as great as 50 percent (and higher, in some cases). Below 15-20 percent slope, channel or ridge terraces are better suited than bench terraces.

CAUTION: Before trying to put steep slopes into crop production, make sure that this can be justified environmentally.

Natural Bench Terrace Formation

Excavated bench terraces require high amounts of hand labor which may not be feasible. It's often more practical to encourage their natural development instead, as is done with the S.A.L.T. method above or with rock walls. Not only is labor saved, but land can be used for cropping (at least for perennials) during this period. Here are some guidelines for natural terrace formation:

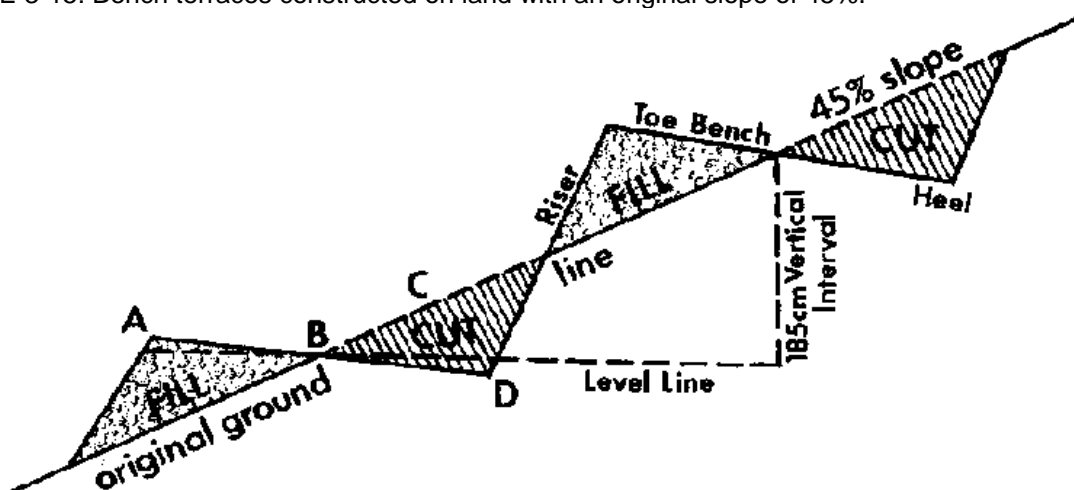
- Natural bench terrace development is best adapted to slopes of about 20-50 percent.
- Rock or vegetative barriers about 1 meter wide are planted on the contour at vertical intervals of about 1.8-2.0 meters. (The horizontal interval can be found by multiplying this by 100/%

slope; i.e. $2 \text{ m} \times 100\%/40\% = 5 \text{ meters}$). Species like elephant grass, jaragua grass, molasses grass, tropical kudzu, and ipil-ipil have worked well in some areas.

- Once the barriers are established, the land can be plowed and cropped. When plowing or hoeing to prepare the ground, the soil should be moved towards the barriers to encourage terrace formation. Cropping and plowing are done on the contour, however.
- Water can usually be allowed to move down the slope through the barriers if they're dense enough.

Some Guidelines for Excavating Bench Terraces

FIGURE 3-15: Bench terraces constructed on land with an original slope of 45%.



Note these features of the bench terrace in Fig. 3-15:

- It is built by digging soil out from the eventual "heel" (D) and using it to fill out the eventual "toe" area (A). You can see that the bench's surface soil will end up being mainly inferior subsoil (with the topsoil buried below) unless a special technique is used which we'll cover below.
- The riser is not vertical but has a backslope of 1/2:1 (i.e. 5 units horizontal distance for every 10 units vertical distance). This is done to make it less likely to cave in.
- The bench has a gentle backslope of about 8% to prevent water from overflowing the "toe" and to promote infiltration.

In addition, here are some other important factors in bench terrace construction:

- As with the contour ditch and barrier system, the terraces should be laid out with a gentle lateral slope (about 0.25%) so that excess water can be moved off the field in a small ditch made along the "heel" area to a protected waterway
- To avoid excessive erosion of the risers, they should be protected with rocks or with dense vegetation like grass or tropical kudzu.
- **CAUTION:** Don't attempt excavation of bench terraces during the rainy season. A partially completed terrace system can be very vulnerable to rainfall erosion or mudslides.
- Whenever possible, consult a conservation specialist before beginning a terracing project.

How to Keep the Topsoil on Top When Building Bench Terraces

Refer to Figure 3-15 above and look at the original ground line. You can avoid burying much of the topsoil with subsoil by first removing the topsoil layer and piling it in what will be the middle of the bench (point B). When cutting and filling to form the bench, leave the topsoil pile undisturbed, and transfer subsoil from area C to area A to form the bench. Now you can spread the topsoil out over the bench.

Wind erosion

Soil loss by wind erosion is most common in drier areas but also can occur in wetter regions during dry weather (wet soils don't blow). It's one of the main factors behind the environmental degradation of regions such as the African Sahel where it's both a cause and effect of desertification and deforestation. It robs the land of its best soil (topsoil) and kills crops and vegetation by abrasion, uprooting, or burial. Irrigation canals and even highways can be buried by windblown soil and sand. Land affected by drought, overcultivation, overgrazing, or wet season rainfall erosion becomes especially susceptible to wind erosion.

The mechanics of wind erosion

Wind erosion occurs when poorly covered soil is exposed to winds higher than about 20 km/hr (12 mph). Movement of susceptible soil is proportional to the wind speed cubed, so it increases rapidly above the threshold wind level (i.e. 8 times more soil is moved at 40 km/hr than at 20 km/hr). Soil particles of 0.1 mm diameter (fine sand) seem to be the most easily moved than either larger (coarser sand) or smaller ones (silt, clay). Soil movement begins when wind abrasion begins to detach tiny soil particles. Once laden with these, the wind's abrasive action markedly increases and dislodges more particles. About 50-75 percent of movement occurs as short bounces along the surface; when larger particles are struck by this bouncing, they can begin rolling and sliding, a process called "soil creep" which can account for 5-25 percent of total movement. Finally, tiny particles can be carried thousands of meters upward and be transported hundreds of kilometers.

COMBATting WIND EROSION

Several things can be done to help control wind erosion:

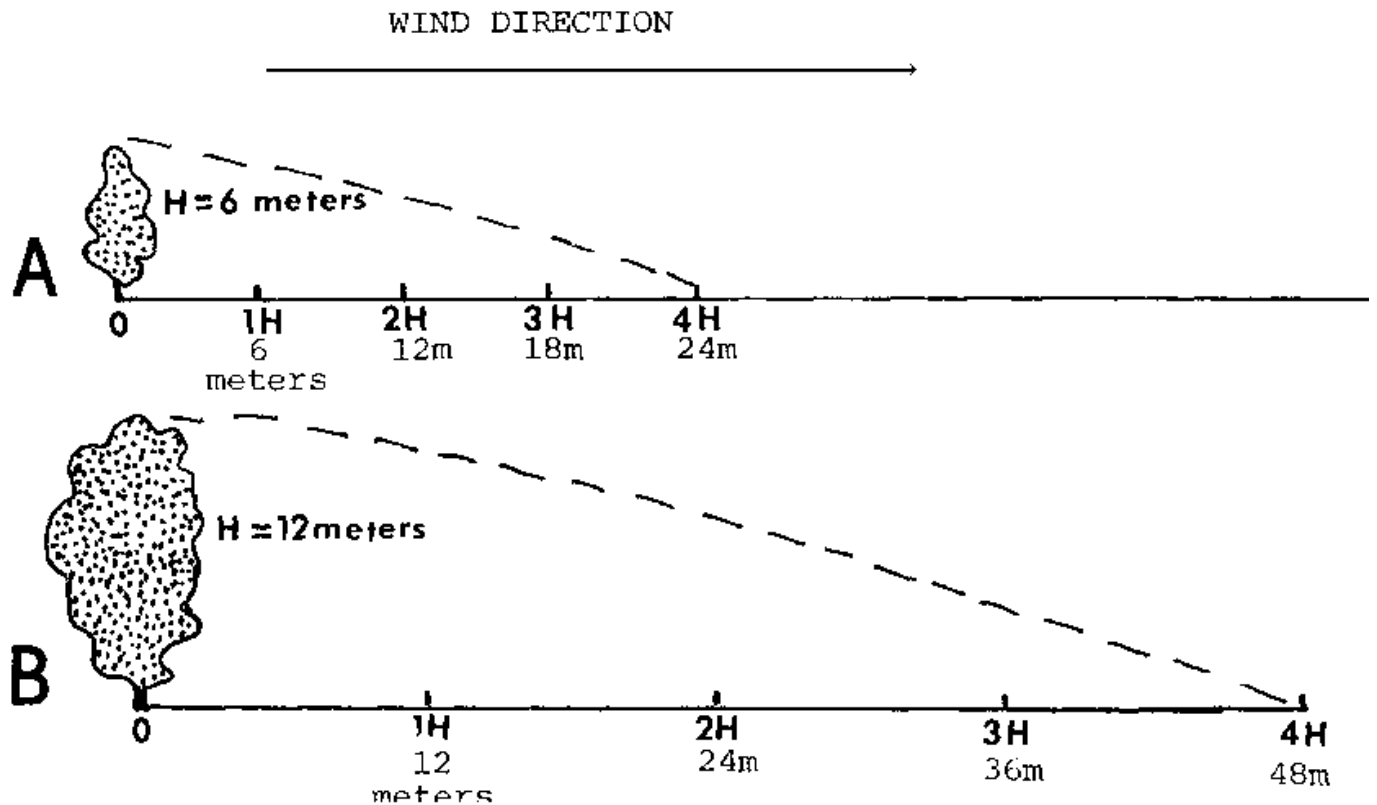
- Maintain the soil surface in a moist condition during periods of wind erosion risk. However, this isn't practical on large areas or where water is scarce.
- Soil in a rough, cloddy condition resists movement better than when pulverized or smooth. Maintaining a good level of organic matter helps aggregate (clump) the particles together. When plowing or other tillage is done, the resulting furrows should be at right angles to the prevailing wind.
- Soil coverage with close-sown vegetation, trees, or mulch can be very effective. A related practice is called strip cropping in which strips of close-sown crops alternate with more open ones across the field at right angles to the prevailing wind.
- Windbreaks (see below).

Windbreaks

In areas of high wind erosion risk, tree windbreaks (also called shelterbelts) offer the most permanent and effective control where land can't be constantly maintained in pasture or trees. They can be used on a small scale for individual fields or garden projects or, on a broader scale, to protect much larger areas (even villages themselves). (NOTE: Some people use the term "shelterbelt" to refer to these larger scale windbreaks, but there's no agreement on this.) Windbreaks consist of a barrier of one or more rows of fast-growing trees planted to the windward side of the area in need of protection. In regions where the prevailing wind comes from more than one direction, two or more windbreaks at right angles to each other may be needed.

Windbreaks can protect a downwind area whose horizontal length is equal to up to 20 times the trees' height (H). The reduction in windspeed will vary with the downwind distance from the windbreak, but at $4 \times H$, the percentage reduction is the same, no matter what the tree height, and usually is about 40% of open speed (see Fig. 3-16). Since the actual force and potential destructive ability of wind is proportional to the square of its velocity, a 20 km per hour wind (i.e. 40% the speed of a 50 km per hour wind) would have only about 16% of the destructive force of a 50 km per hour wind (i.e. $20^2 = 400$; $50^2 = 2500$; $400/2500 = 16\%$).

FIGURE 3-16: At a downwind horizontal distance of $4 \times$ tree height (H), the wind speed will be about 40% of open velocity. For example, if wind speed is 40 km per hour (open speed), it will be about 16 km per hour at location 4H (24 meters downwind in field A and 48 meters downwind in field B).



Promoting Windbreaks

It's not always easy to convince farmers or villagers of the value of shelterbelts. They take 2 or more years to begin being effective and require labor to plant, maintain, and protect in the meantime. However, once established, they not only provide wind erosion protection, but can supply forage for animals (leaves, pods), and wood for fuel and fencing when pruned; some like jujube (*Zyziphus mauritiana*) also provide edible fruit. Dry season vegetable gardens in regions such as the Sahel greatly benefit from windbreaks; they not only lessen wind and sand damage, but lower plant water use rates by reducing the force of hot, drying winds.

Although attempts to introduce windbreaks have had mixed results, there are some success stories. For example, some 250 km of double-row shelterbelts have been recently established in the Maggia Valley of Niger over a 7 year period. Substantial progress has also been made in the Sine-Saloum area of Senegal. In some cases, relief agencies have made windbreak implementation a necessary prerequisite for assistance in other related areas such as the installation of permanent wells for dry season market gardens.

Windbreak Design Considerations

Successful windbreak establishment is another very location-specific practice. You'll first want to read up on the subject and get assistance from your country's forestry service and other reliable sources. Once aware of the possibilities (and limitations), it's vital to confer with the villagers and farmers involved to sound out their needs and expectations, as well as to make sure they realize the labor, care, and time frame involved.

The following guidelines are meant to give you some basic facts about windbreaks to help you determine their feasibility and lay the ground for further investigation and intelligent discussion with windbreak specialists.

- Choosing Species: Trees selected can be native or introduced, as long as they're known to be adapted to the area's rainfall, temperatures, and soil conditions. Some other desirable features are:
 - Rapid early growth (2-4 meters/year).
 - Resistance to local insects, diseases, and nematodes.
 - Easily established and maintained.
 - A dense (not bushy) crown (top portion) is more resistant to wind damage.
 - Legume species like Acacia and Parkinsonia have especially nutritious leaves and pods for fodder and also fix nitrogen.
 - Long life.
 - Evergreen or at least in full foliage during the windy season.
 - Quick regrowth when pruned.
 - Multiple uses such as forage, fruit, and wood for fuel and fencing, etc.
- It's often hard to find one adapted species that combines all these features, so two or more are often used together. Here are just a few examples of windbreak tree species adapted to drier tropical regions (scientific names in parentheses):
 - Neem tree (*Azadirachta indica*)
 - Eucalyptus species (esp. *E. camaldulensis*)

- Christ thorn (*Zyziphus spina-christi*)
 - Jerusalem-thorn (*Parkinsonia aculeata*)
 - Tamarisk (*Tamarix aphylla*)
 - Australian beefwood (*Casuarina equisetifolia*)
 - Egyptian thorn (*Acacia nilotica* = *A. scorpioides*)
 - Euphorbia (*Euphorbia balsamifera*) [Especially well suited to barren sand]
 - Windbreak Orientation: Windbreaks should be oriented at right angles (or no less than 45 degrees) to the prevailing wind. In regions where the prevailing wind comes from more than one direction, two or more windbreaks at right angles to each other may be needed.
 - Intervals between successive windbreaks can be up to 20 times the tree height. In dry regions, average tree height reaches about 5-7 meters without irrigation beyond the initial stages; in this case, a distance of 100-140 meters between windbreaks would be appropriate. In wetter regions (or under irrigation), tree height will reach 10-15 meters, allowing for a 200-300 meter interval between windbreaks.
- NOTE: Temporary barriers may be needed between permanent windbreaks during the first 5 years of growth.

- Density: Surprisingly, the best windbreaks are usually moderately dense. Overly dense (impermeable) ones cause a turbulence effect on the downwind side that considerably reduces the zone of downwind protection. Densities of about 60-70 percent have proven the most effective in providing good wind protection with minimum turbulence.
- Width: In practice, windbreak width usually is determined by the amount of land, labor, and water available. One to three row windbreaks are the most practical for drier areas. Two rows of *Eucalyptus camaldulensis* are usually sufficient to form an effective permeable barrier. A species like *Conocarpus lancifolius* with a compact crown (good distribution of branches from top to bottom) can be effective with just one row. However, such single-row plantings have no safety factor; if holes develop, wind funneling can cause considerable damage. Multiple-row windbreaks facilitate cutting (for firewood, etc.) and also replanting (needed when growth slows, usually after 15-25 years); these operations can be done one row at a time, leaving at least one row standing.
- Combining Species: To provide an effective vertical distribution of foliage, it may be desirable to combine a low-growing species like *Acacia* with a tall-growing one like *Eucalyptus* in a 2-3 row configuration (see Fig. 3-17).

FIGURE 3-17: Examples of multiple-row windbreaks. An effective triangular configuration (A, B) can be obtained by combining different species, placing the tallest in the center. A rectangular configuration (C) results from using multiple rows of the same species; it is also satisfactory, as long as at least one row has foliage down to ground level.



- Between-row spacing: 3-4 meters for fast growing types.
 - In-row tree spacing: Overly close spacings may cause crowding that results in dense growth of the top portion but sparse growth below. A final in-row spacing of 1-1.5 meters for shrubs and 2-3 meters for trees is usually best. To provide quicker closure, seedlings can be planted twice as close and then later thinned by removing every other one.
- Establishing and Managing Windbreaks

- Seedlings may be available from a forestry station in the area or may need to be grown. Most common species are grown in polythene bags and are ready for setting at 6-9 months. Some like *Parkinsonia* take only 3 months. Others like *Tamarisk articulata* can be planted directly from cuttings.
 - Good soil preparation of the windbreak planting area is much more important than for normal forest planting in order to encourage a high survival rate and rapid growth.
 - Irrigation is needed in dry regions, during the first 2-3 years. When young, light but frequent waterings (about once every 7-10 days) are best; later on, heavier but less frequent ones will encourage deep rooting. It's often advantageous to plant at the start of the rainy season to take advantage of the moisture. Making micro-catchments (shallow depressions) around the seedlings will help concentrate water near them. Mulching will reduce water evaporation but may attract insects or termites.
 - Protection from livestock, illegal cutting, weeds, insects, and fire is vital, especially during the first few years of growth.
 - Pruning: Depending on the species, pruning of the lower branches may be needed at an early age to promote height growth. During the fourth or fifth years, further pruning may be needed to encourage horizontal growth.
 - Most shelterbelts have a life of roughly 15-25 years, after which growth slows down too much. Cutting and replanting will be needed. In a multiple-row windbreak, the first cut is made on the downwind side about halfway through the normal rotation period. The remaining windward rows offer adequate protection while the replanted row becomes established. The second cut (windward side) and others are done at the normal rotation period (15-25 years).
- NOTE: For further information on windbreaks, refer to Appendix H.

Chapter 4: Seedbed preparation

-Getting Crops Off to a Good Start

The what and why of tillage

Tillage is the use of implements to prepare land for planting. Many Third World small farmers who lack equipment (or whose land is very steep or rocky) will prepare ground by slashing and burning the vegetation, followed by making seed holes with a planting stick or hoe. In cases where tillage is used, it has 5 main purposes:

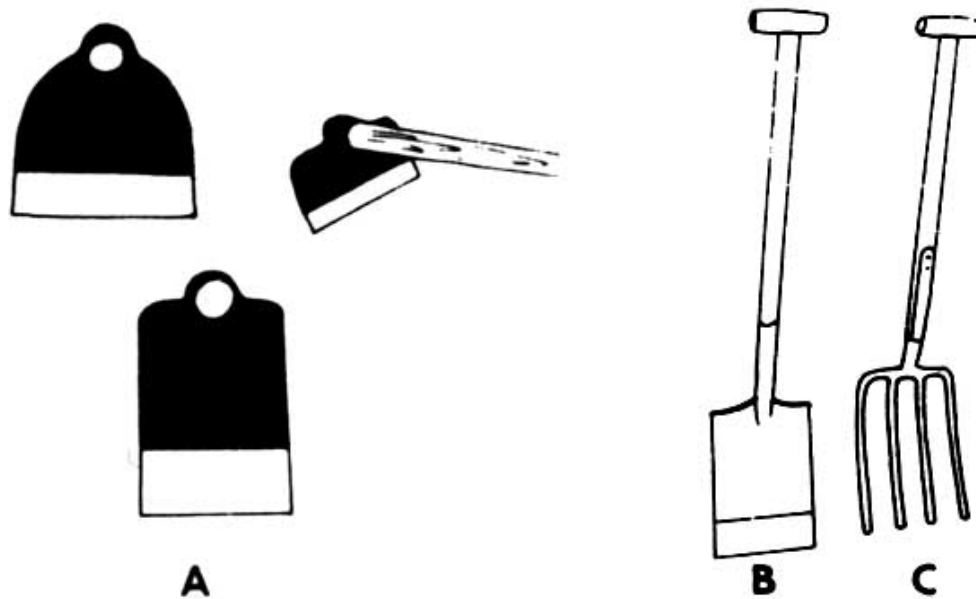
- To break up clods and loosen the topsoil to encourage seed germination, seedling emergence, and root growth. Most tractor- and animal-drawn planters require a tilled seedbed for successful operation.
- To chop up and/or bury the previous crop's residues so they won't interfere with the new crop.
- To control weeds. An ideal seedbed is completely free of visible weeds at planting time.
- To incorporate (mix into the soil) fertilizers or liming materials.
- To shape the type of seedbed best suited to the specific soil, crop, and rainfall conditions (e.g. raised beds, ridges, flat beds, sunken beds, etc.).

Common tillage equipment

NOTE: For a more detailed description of tillage equipment, see the PC/ICE Traditional Field Crops Manual.

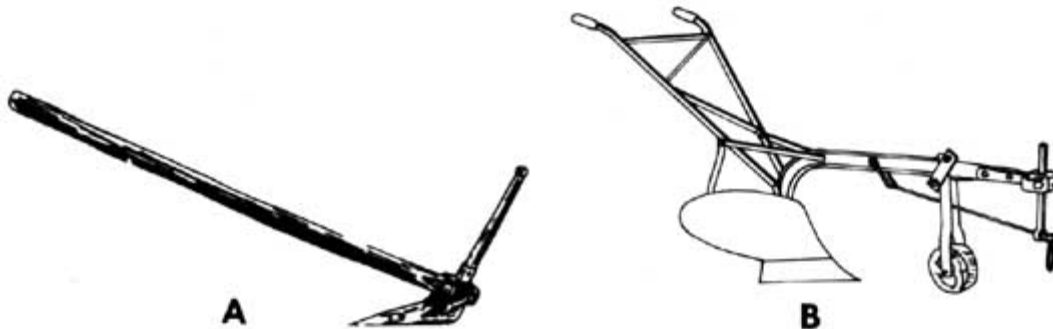
Hand Implements: Digging hoes, shovels, turning forks, and rakes are very effective for smaller areas. By using the double-digging method (described later in this chapter), the subsoil can be loosened too.

FIGURE 4-1: Digging hoes (A), digging spade (B), digging fork (C).



Wooden Plow: Designs date back many centuries; they're animal drawn, and some have a metal tip. They do not invert (turn over) the soil or bury crop residues like a moldboard plow but basically make grooves through the soil. Wooden plows penetrate about 15-20 cm deep.

FIGURE 4-2: Wooden plow (A), moldboard plow (B)

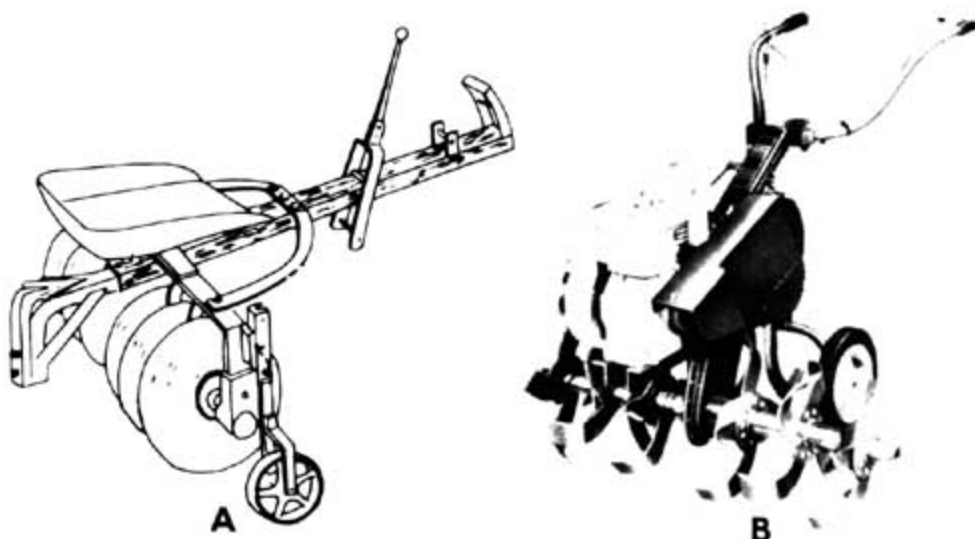


Moldboard Plow: Depending on its size and the condition of the soil, it penetrates 15-25 cm deep and inverts the furrow slice, making it very effective for burying weeds and crop residues. (Bulky residues like maize stalks must be chopped up first.) Both animal- and tractor-drawn models are used. Moldboard plows aren't as well suited to dry soils, as disk plows and don't handle rocky soils as well. They also don't work well in sticky, clayey soils.

Disk Plow: Better suited than the moldboard to hard, clayey, rocky, or sticky ground but won't bury residues as well; however, this is an advantage in drier areas where leaving residues on the surface cuts down wind and water erosion and reduces moisture evaporation. Nearly all disk plows are tractor drawn.

Rototillers (rotovators) are available in self-powered and tractor-drawn models. They thoroughly pulverize the soil and partially bury crop residues. Heavy duty models can be used for a once-over tillage job. However, their power and fuel requirements are high, and they can easily over-pulverize a soil and destroy its beneficial crumb structure.

FIGURE 4-3: Animal-drawn disk harrow (A) and gasoline-powered rototiller (B).



Disk Harrow: These are available in animal- or tractor-drawn models and are commonly used after plowing to break up clods, control weeds, and smooth the soil before planting. They are also useful for chopping up coarse crop residues before plowing, but heavier models with scalloped (notched) disks are best for this purpose. Disk harrows are expensive and prone to frequent bearing failure unless regularly greased. Large, heavy duty versions called Rome plows, which are drawn behind big tractors, can sometimes substitute for plowing. Disk harrows cut, throw, and loosen the top 8-15 cm of soil but pack down the soil immediately below that. Repeated harrowing, especially when the soil is moist, can cause compaction in the lower topsoil.

The abuses of tillage and how to avoid them

Tillage can either enhance or destroy good soil filth (workability). Sure, plowing and harrowing break up clods and loosen the topsoil, but the stirring and shearing action stimulate the microbial breakdown of beneficial soil organic matter and may also over-pulverize the soil. Tractor wheels, animal hooves, (and even foot traffic) can cause soil compaction (especially on wet, clayey soils), which can seriously impair root growth and drainage. In mechanized farming, it's common for a traffic pan (compacted zone) to develop on many soils (even sandy ones) at a point right below tillage depth. Plowing clayey soils when they are overly dry can produce large, brick-hard clods that may first require rainfall or watering before they can be broken up. Tilling clayey soils when they are wet can seriously affect their filth.

The two implements most likely to harm filth are the disk harrow and the rototiller. Many farmers overuse the disk harrow by making repeated passes to kill weeds or smooth the soil. Unfortunately, harrowing kills one stand of weeds but encourages another by bringing up more weed seeds closer to the surface where there is sufficient oxygen to trigger germination.

The Ideal Seedbed

The only portion of the seedbed that needs to be reasonably clod-free is the narrow row zone where the seeds are planted. In fact, you're actually better off keeping the spaces between the rows in a cloddy condition to discourage weed germination and help maintain filth. Since the 1960's, minimum tillage systems such as plowing and planting in one operation or using specially designed planters to plant directly through crop residues into unplowed ground have become increasingly popular for field crops like maize in the developed countries. These methods have definite potential for the Third World, too. For example, the International Institute for Tropical Agric. (IITA) in Nigeria has been adapting such reduced tillage methods to small farmer conditions (see address in Appendix G). They have developed hand-pushed planters that can successfully

plant maize and cowpeas through vegetation that has been slashed down (or killed with a herbicide) and left on the soil surface as a beneficial mulch. No tillage is used with this method.

Making the right seedbed for the crop, soil, and climate

NOTE: Seedbed preparation is very location-specific and varies with climate, soil type, crop, management level, and available equipment. Local farmers usually have good seedbed skills, so beware of tampering with local methods before thoroughly testing new ones.

What Kind of Seedbed?

There are basically 3 types of seedbeds: flat beds, raised beds, and sunken beds. The best type to use depends much more on the particular climate and soil conditions than on the crop.

Flat Beds

Flat beds are used where water availability is adequate and there are no drainage problems. In some areas, crops like maize, sorghum, beans, and potatoes are started out on a flat bed; as the season progresses, soil is thrown into the crop row to mound up the plants; this is called "hillingup" and is done to control in-row weeds, provide support, and improve drainage. (Potatoes are also hilled up to keep the developing tubers covered with soil.) Hilling-up only works with plants that have enough stem height and leaf clearance to tolerate partial burial.

Raised Beds

Crops can also be grown on raised-up beds or ridges. They are especially advantageous for clayey soils under high rainfall or wherever else drainage is likely to be poor. They can also be used in many other situations. Where crops are furrow irrigated, raised beds or ridges are essential so that the water can flow down the furrows between them.

Height of raised beds: Raised beds are usually 10-30 cm high. The best height depends mainly on soil texture and moisture considerations. For example, raised beds are often 20-30 cm high on clayey soils under high rainfall where poor drainage is likely to be a problem. On coarser-textured soil under the same conditions, bed height might be 15-20 cm. When raised beds are used in drier conditions, a bed height of 10 cm or less may be best to avoid excessive moisture loss due to evaporation from the exposed sides.

Width of raised beds: Typically they are 100-130 cm wide.

Raised beds may have several advantages:

- Much better drainage compared with flat or sunken beds.
- They provide a double layer of topsoil, because they're made by dragging in topsoil from the surrounding alleyways. (Because of this, they're also likely to be looser than flat or sunken beds.)

- In temperate regions, raised beds warm up more quickly in the spring, which may benefit cold-sensitive crops and even permit earlier planting.
- Plants on raised beds are easier to reach when doing hand operations such as weeding and thinning.

Raised beds usually aren't a good choice during the dry season, because they dry out more quickly than flat or sunken beds; also, water tends to run off them and be lost into the alley-ways. These disadvantages can be partly overcome by mulching the bed with straw or rice hulls, making a lip around the bed's edge to reduce run-off, and by reducing bed height to 10 cm or less (see Fig. 4-4).

FIGURE 4-4: Two types of raised beds. Bed A is best suited to high-rainfall areas. Bed B has a lip around all 4 sides which helps prevent water from running off (helpful in drier conditions).

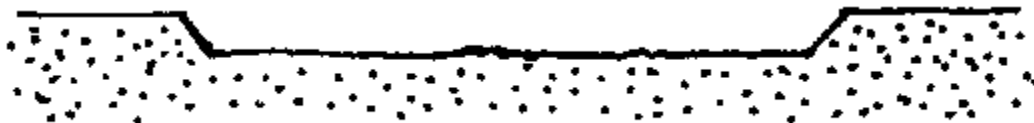


Sunken Beds

In dry regions, especially on sandy soils with low water-holding capacity, vegetables can be planted in sunken beds (i.e. shallow basins) about 100-130 cm wide and 2-5 cm below the surrounding soil level. Sunken beds conserve water much more effectively than raised beds for 2 reasons:

- Sunken beds don't have the exposed sides of raised beds from where considerable moisture can be lost by evaporation.
- None of the applied water is lost by runoff.

FIGURE 4-5: A sunken bed. Depth shouldn't exceed about 4 cm.



One disadvantage of sunken beds is that some topsoil is lost in the usual method of construction. (They're made by pulling off soil from the bed area and placing it in the surrounding alleyways). This probably won't affect crop growth, as long as the topsoil is of normal depth (at least 15 cm) and enough compost or manure is added. Here are 2 ways of building sunken beds without sacrificing topsoil:

- First take off the topsoil, and then replace it after removing enough subsoil to sink the bed enough.
- Make a "pseudo" sunken bed by mounding alleyway soil around the bed's borders. This will work well in clayey soil, but border dikes made of sandy soil may wash out when the bed is watered.

One variation of sunken beds is furrow planting in which crops like maize, sorghum, and beans are planted in the furrow bottom between two ridges where soil moisture is higher and less easily

lost. Soil can then be thrown into the furrow as the season progresses to control weeds and improve drainage if rainfall increases.

How deep should land be tilled?

Most seedbed preparation methods use a plow or digging hoe to loosen the soil to a depth of 1520 cm (i.e. the topsoil). There are 2 situations where deeper tillage may be cost-effective, though not always, by any means:

- Encouraging roots to enter the subsoil by breaking up a pan (compacted layer) may enable them to tap into a valuable moisture reserve; this can make a crucial difference in a drought, especially for deep-rooted crops (e.g. maize, sorghum) grown under rainfed conditions. Loosening a pan may also improve soil drainage.

- In very hot conditions (e.g. the Sahel during the period from March through June) deep tillage may allow roots to grow deeper into cooler, more hospitable soil. The value of deep tillage is commonly overrated for a number of reasons:

- Power and labor requirements increase greatly, especially since the subsoil tends to be more compact. With hand tools, deep tillage is seldom practical on anything but small plots.

- About 60-80% of most crops' roots are found in the topsoil, even in high-yielding fields.

- Subsoils that are poorly drained or too acid won't allow much root growth, no matter how well loosened or enriched. Also, it's not unusual for the soil below a hard pan or clay pan to be compacted and poorly drained.

- Loosening a compacted subsoil is likely to be only temporarily effective unless a soil conditioner (sand, rice hulls, etc.) is added, as well as fertilizer. This may be feasible using hand tools but is very laborious.

- On large fields, tractor-drawn subsoilers (long, narrow shanks that penetrate up to 60 cm deep) can be used to break up compacted layers (pans). Results vary from poor to good, depending on the type of pan, its wetness, and the characteristics of the soil below it.

Hardpans (natural layers that remain cemented whether wet or dry) and traffic pans (compacted layers right below normal tillage depth that are caused by machinery traffic) can usually be successfully fractured while dry. However, subsoiling claypans (natural, dense, clayey layers) often gives disappointing results for 2 reasons. First, they're often continually wet (unless the dry season is long) and aren't subject to fracture in this condition. Secondly, soil below such claypans is often compacted and poorly drained, too.

How fine a seedbed?

Seedbed "fineness" refers to the degree to which clods are broken down and the soil smoothed over. The need for this depends mainly on seed type, seed size, and whether hand planting or mechanical planting will be used.

- Seed type: Monocot plants like the cereals (maize, sorghum, etc.) have one cotyledon (seed leaf) and break through the ground in the shape of a spike which helps them handle some cloddiness. Dicot plants (pulses like beans, cowpeas, peanuts, and virtually all vegetables) have 2 cotyledons and emerge from the soil in a much more blunt form, actually dragging the 2 seed leaves (formed from the 2 halves of the seed) with them. They have less clod-handling ability than most monocots, although seed size also makes a difference.

- Seed size: As a rough rule, the larger the seed, the less the need for a fine seedbed. Large seeds have more energy and can also emerge from greater depths. A seed like maize is not only large but is a monocot too, so it has especially good clod-handling ability. Peanuts, beans, and most other pulses are large seeded, but this advantage is partly offset because they are dicots. The small seeds of millet and sorghum lack some power, but being monocots is a help. Note that smaller seeds (i.e. lettuce, cabbage, onions, amaranth, require shallower planting than larger seeds (i.e. pulses, okra, maize, squash, etc.) and that a cloddy seedbed makes it difficult to be precise with planting depth.

- Hand vs. mechanical planting: Farmers who hand plant can usually get by with rougher seedbeds for several reasons. It's easier to control planting depth when hand seeding and large clods can be pushed aside. Also, it's common under hand planting to plant several seeds per hole, which provides more power for breaking through the soil.

Some handy seedbed skills for intensive vegetable production

In this section, we'll cover these useful seedbed skills:

- Seedbed layout for intensive vegetable gardening
 - Double-digging
 - Dealing with heavy clay soils
 - Dealing with soil crusting problems
 - Making up a soil mix for nursery seedboxes
- Seedbed layout for intensive vegetable gardening: The Bed-and-Alley System

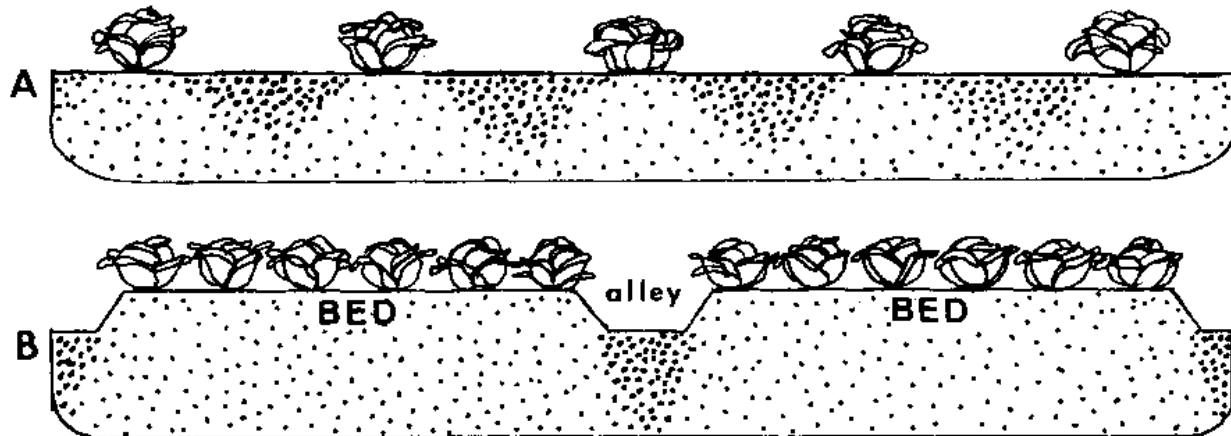
Western vs. Intensive Seedbed Layout

A typical Western-style vegetable garden, with each of its rows wide enough to walk down, makes poor use of space. In this type of garden, the rows are anywhere from about 60-90 cm apart, even though the plants' foliage and root spread may cover only a portion of this (see Fig. 4-6a). In fact, the usual row spacings recommended by most county extension offices in the U.S. (e.g. 90 cm for peppers and cabbage, 76 cm for turnips, beets, and lettuce, 60 cm for radishes) result in a garden with only about 30 percent of its space occupied by the plants and their roots; the rest of the area is essentially walking space! Such a layout wastes valuable land, water, and fertilizer; it also requires more time and labor for weeding and watering. In addition, providing a walkway between every row greatly promotes harmful soil compaction.

The bed-and-alley system of intensive gardening is an alternative to the wide-row system and may offer a number of advantages under non-mechanized conditions (the system isn't suited to animal-or tractor-drawn operations once the beds are planted). Here are the features and possible benefits of the bed-and-alley system:

- The garden is arranged into beds of closely-spaced plant rows; walkways (alleyways) are placed only between the beds instead of between each row (see Fig. 4-6b).
- The beds' widths can range from about 100-130 cm, which enables all the plants and bed area to be easily reached without walking in the bed. The beds (they can be flat, raised or sunken, depending on soil and rainfall conditions) are best kept to 10 meters or less in length so that alleyways can be run up and down, as well as across the garden to facilitate access. The alleyways can be as narrow as 50-60 cm, although occasional wider ones (up to 100 cm) are useful for wheelbarrow traffic.

Figure 4-6: Wide-row gardening system (A). Bed-and-alley system (B).



- Since there's no need to walk in the beds, row spacings can be based solely on what's needed for plant spread, which is usually much less. For example, cabbage rows can be 30-45 cm apart (vs. 90 cm), leaf lettuce rows 15-20 cm apart (vs. 75 cm), and carrot rows 5-10 cm

apart (vs. 75 cm). In the case of root and leaf vegetables, the between-row spacing can be as narrow as the in-the-row spacing. Depending on the crop, anywhere from 1.5 to 15 times more plants can be grown per sq. meter of land (bed and alley area included) with the intensive system.

- Using 120 cm-wide beds and 60 cm-wide alleyways, the intensive system will give a land-use efficiency of about 65 percent, compared to about 30 percent for a typical wide-row garden. In other words, such an intensive layout would consist of 65 sq. meters of actual bed area and 35 sq. meters of alleyway area per each 100 sq. meters.
- Aside from the savings in space, labor, and water, the intensively-spaced plants eventually form a “living mulch” with their leaves that effectively shades most of the bed's surface. This reduces water losses from surface evaporation, helps suppress weeds, and cools the soil (beneficial for roots of cool-season crops like cabbage grown in hot weather). (Note that under high-rainfall, humid conditions, such close plant spacings may promote the development and spread of some plant diseases, especially fungal leafspots.)

Double-digging

What is Double-Digging?

As we've seen, most land preparation methods loosen the upper 15-20 cm of soil (the topsoil). Double-digging is a method of loosening, as well as improving/enriching, a much deeper layer of soil down to 40-60 cm which includes some of the subsoil, too.

Benefits of Double-Digging

Under appropriate conditions, double-digging may have some important benefits:

- Yields may be increased due to better and deeper root growth and improved aeration and water availability. In very hot areas, it may allow roots to grow deeper into cooler, more hospitable soil.
- In some cases, double dug plots may produce the same yield on less area (1/2 or less in some cases); this means that less land, and, more importantly, less water and labor may be needed.
- Where double-digging results in more production on less land it may make it feasible to use other possibly beneficial practices like crop rotation and green manure crops. (These 2 practices are explained in Chapter 8.)

Limitations of Double-Digging

- Double-digging is not a “cookbook recipe” for increased yields. Like many so-called “improved” practices, it should first be tested locally before promoting it.
- It requires much more time and labor than standard land preparation (probably at least 3 times as much), and therefore is seldom feasible on anything but small plots.
- If the subsoil is very acidic (below pH 5.0-5.5), it may require liming to enable root development there.
- Double-digging will not solve subsoil drainage problems caused by a high water table.

Situations Most Likely to Benefit from Double-Digging

Double-digging is best suited where crops are grown in beds (flat, raised, or sunken) that have alleyways around them. Such a double-dug bed will not be recompactd by foot, animal, or machinery traffic, as would be the case with a wide-row, open-field plot. Beds are most likely to respond well to double-digging under the following conditions:

- Dense, compacted! clayey subsoils
- Deeper-rooted crops like tomatoes, eggplant, okra, squash, and beans may benefit more than shallow-rooted crops like onions, lettuce, cabbage, and radish. However, even some shallow-rooted crops can put down roots 40-50 cm deep with good soil conditions.

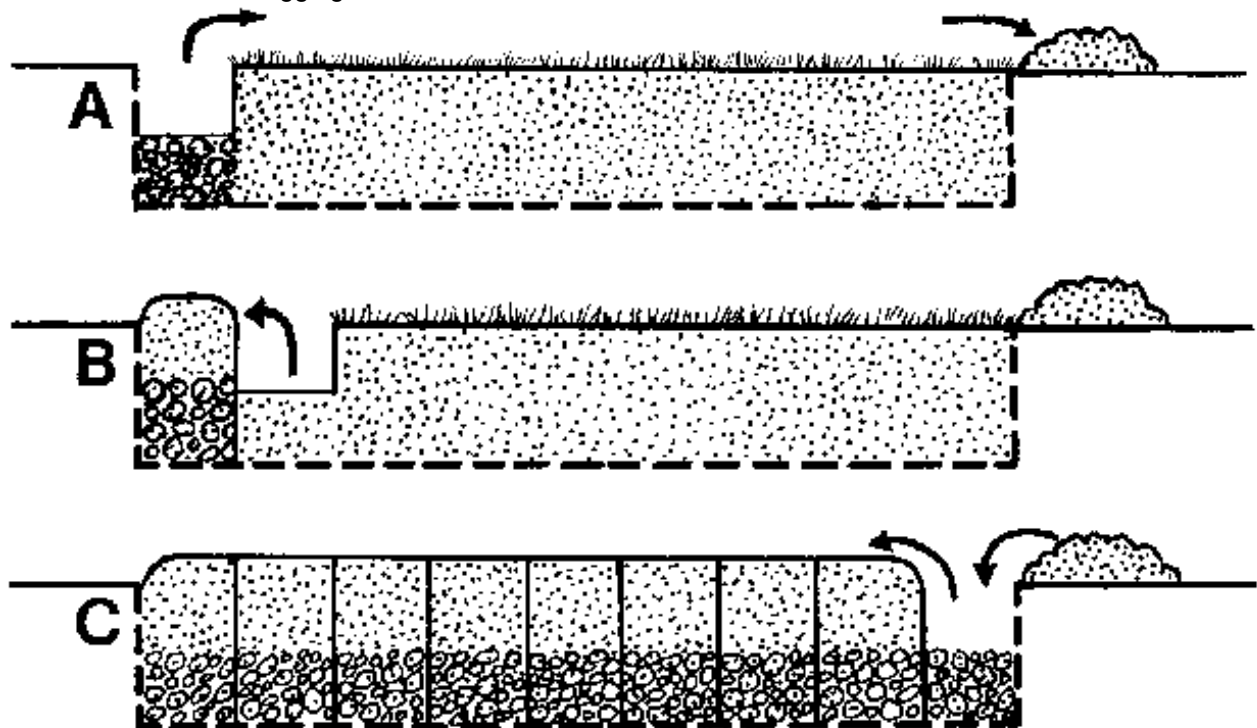
- Hot-dry climates where increased root penetration is likely to improve water availability and allow roots to enter cooler soil.

How to Double-Dig

The best way to learn double-digging is to do it. A shovel is sufficient, but a digging fork or pick may come in handy for very hard subsoils. Here are the steps:

1. Stake out a 1 x 4 meter bed.
 2. Start at one end and dig out a trench 30-40 cm wide to the depth of your shovel blade. Carry the soil to the other end of the plot and deposit it just outside as in Figure 4-7a.
 3. Now add a layer of compost or manure at least 2 cm thick to the bottom of the trench. Work it into the subsoil, ideally to the depth of the shovel blade. It's not necessary to invert the subsoil, as long as the organic matter can be mixed into it. Although some gardening manuals give dire warnings about mixing different soil layers, this is unlikely to cause any problems. Soil conditioners like rice hulls or peanut hulls can be added along with compost or manure; however, if used by themselves, they're likely to cause a temporary nitrogen tie-up. (Refer to the section on soil conditioners in Chapter 8.)
- NOTE: Double-digging will be largely ineffective unless you add manure, compost or some sort of soil conditioner to the subsoil; otherwise, it may soon recompact and also will remain infertile, thus discouraging root growth.
4. Now dig the next 30-40 cm-wide trench, but this time throw the soil into the trench you made in Step 2. (See Figure 4-7b.)
 5. Repeat Step 3 with the soil in the bottom of the 2nd trench.
 6. Continue this sequence until you reach the end of the bed.
 7. After loosening and enriching the subsoil in the last trench, fill in the trench with the soil that you carried to that end of the bed in Step 2. (See Fig. 4-7c.)

FIGURE 4-7: Double-digging a bed.

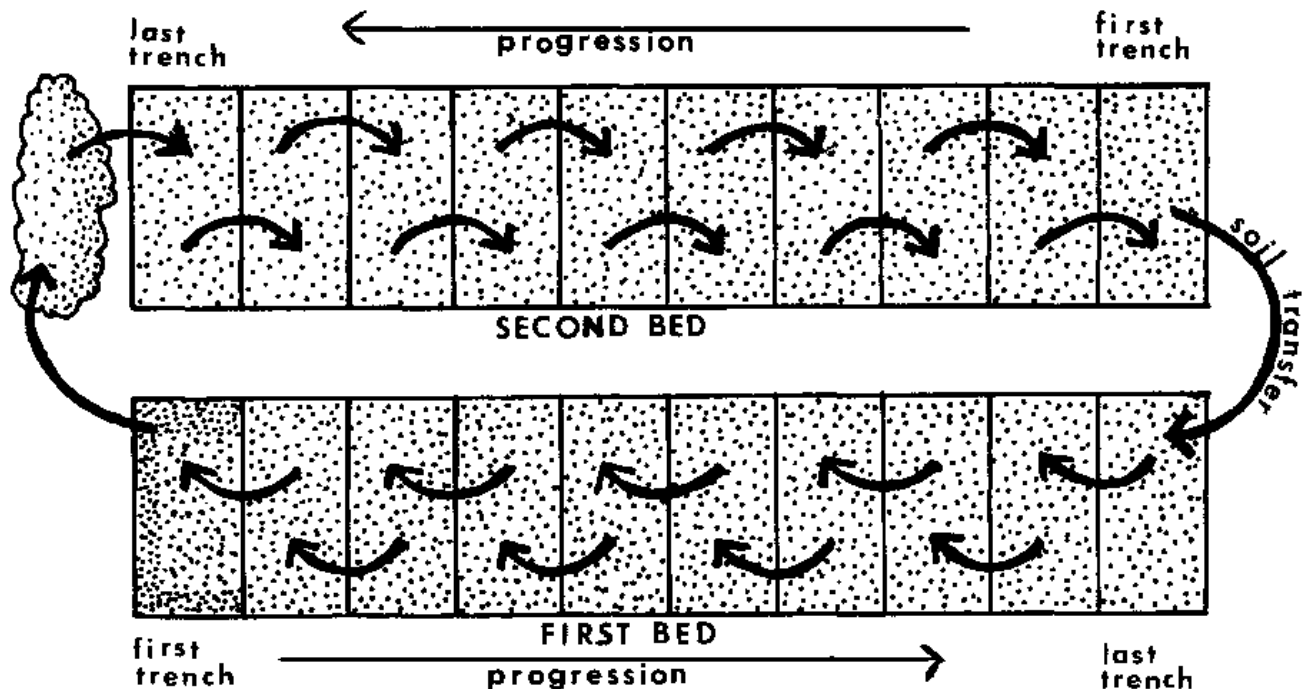


A shortcut: When double-digging a series of adjacent beds, you can avoid carrying the soil from the first trench to the other end of the bed (see Step 2 above) by using the method shown in Figure 4-8.

How often to double-dig?: Double-digging a plot once a year should be sufficient if the bed-and-alley,

system is used, since it will help avoid recompaction. It may take several years of annual double-digging to measurably improve the soil; after that, you may be able to do it less often.

FIGURE 4-8: Shortcut method for double-digging adjacent beds.



How to deal with clayey soils

Tillage, bed construction, and planting can become very difficult or even impossible when clayey soils are too wet or too dry. This is because they have a very narrow moisture range within which their filth (workability) is satisfactory. Aside from adding sand and organic matter (see Chapter 2), there are several other techniques that will help:

- Whenever possible, allow overly wet, clayey soils to dry out to the point where filth again becomes satisfactory before attempting to work them. Otherwise, you will actually worsen the soil's condition.
- Pre-watering dry, clayey soils a day or two prior to working them can do wonders for filth. Where the entire topsoil is very dry, apply at least 25 liters of water per sq. meter. Allow the soil to dry to a point where it has lost much of its stickiness and can be worked without producing clods that resist being broken down well by hoeing. You may also want to try doing the initial tillage of the soil while it's still dry and then applying water before breaking up the clods.
- Coarse materials like sand and rice hulls are excellent filth improvers for clayey soils. If in short supply, first prepare the bed for planting and then hoe in the material into the top 2-5 cm of soil. This will greatly improve the filth of this shallow planting layer and facilitate seed sowing and seedling emergence. Another way to efficiently utilize limited amounts of soil conditioners is to apply them in narrow strips centered over the rows.
- On clayey soils, seedling emergence from small vegetable seeds can be greatly improved by covering them with sand, compost, or sawdust instead of soil. Covering the seedbed with a pre-emergence mulch of hay or newspaper will help keep the soil moist for sprouting and allow for shallower planting.

How to handle soil crusting problems

Some soils high in clay or silt and in poor filth will form a cement-like crust at the surface each time it dries out. This can seriously affect seedling emergence, especially in the case of the blunt dicot seedlings (the ones that emerge with 2 seed leaves). Here are some suggestions for

handling soil crusting:

- Make regular additions of compost or manure to maintain a healthy level of soil organic matter which helps counteract the tendency to crust.
- Cover small vegetable seed with sand or sawdust instead of the soil.
- Work in sand into the top 2-3 cm of soil.
- Apply a pre-emergence mulch to the soil after planting to help keep the soil surface moist and free from crusting. It also will absorb the impact from rain or overhead watering which encourages crusting by packing the soil. Straw or dried grass works well but must be removed as soon as seedlings begin emerging or they'll quickly become spindly and weak due to lack of sunlight. However, in some cases, such mulches do more harm than good by attracting harmful insects like crickets, ants, and termites. You can also try a "grow-through" mulch of light, fine material like rice hulls or sawdust which doesn't need to be removed at seedling emergence.

How to make up a seedbox soil mix

If you raise vegetable transplants using seedboxes, you'll quickly find out that straight soil, by itself, seldom works well as a growing medium. When confined to a shallow seedbox or pot, most natural soil becomes very poorly drained in the bottom half of the container, no matter how many drainage holes you make. Even lining the bottom with shells or pebbles won't help much. That's because there's no soil below to provide a suction force to draw the excess water away -gravity by itself just isn't strong enough. The same thing happens when you hang wet clothes on the line a lot of water collects at their bottom end. So, with seedbox soil you'll want to make up an extra-coarse soil mix that will facilitate drainage yet still hold enough moisture. Another advantage of soil mixes is that they're lighter than regular soil which makes it a lot easier to move the seedboxes around.

Here are a few recipes for soil mixes for seedboxes or other containers - try out your own, too, and ask local farmers for their suggestions.

NOTE: As with in-the-ground nursery seedbeds, seed box soil mixes should be sterilized by heat or other method prior to planting to control diseases and nematodes.

- Mixing rice hulls with soil has proven very successful. One example: Philippines horticulturists recommend mixing rice hulls with clay loam soil at a 2:1 ratio by volume and then adding 1 gram of single superphosphate (0-20-0) and 1 gram of 14-14-14

per liter at sowing. Another gram of 14-14-14 per liter is applied at 10 days and again at 20 days after sowing. Rice hulls have a strong capacity to tie up nitrogen and are also low in other nutrients, so that's why the chemical fertilizer is added. (N tie-up is explained in Chapter 6.)

- A 1:3 sand-compost mix. Rotted coconut husk fibers passed through 1/4-3/8 inch (6-10 mm) hardware cloth can be used to make a great instant compost.
- A 1:1:1 sand-soil-compost mix.

Chapter 5: Watering vegetables: When? How Often? How Much?

NOTE: This chapter focuses on hand-watering vegetables during the dry season. For information on furrow irrigation of vegetables and field crops, refer to the bibliography in Appendix H.

It pays to use water wisely

In the tropics, especially in semi-arid regions, most vegetable production occurs in the dry season, meaning that virtually all the water needed must come from irrigation. Even during the rainy season, dry spells may be common and supplemental watering necessary.

Although water is usually in short supply during the dry season, it's often used inefficiently. This not only wastes water, but lowers crop yields and quality.

Some common watering mistakes and their effects

- **Watering too shallowly:** Roots won't grow downward into dry soil, so shallow watering leads to shallow rooting. Deep rooting not only enables plants to absorb more nutrients, but also permits longer intervals between waterings. It's important to understand that both frequent, light watering and less frequent, heavier watering can result in insufficient water penetration if the total amount applied per week is too small.
- **Watering too deeply:** This is very easy to do with shallow rooted crops or with sandy soils because of their low water-holding capacity. The excess water moves down beyond the root zone, not only wasting it but carrying away mobile nutrients like nitrate nitrogen and sulfur. (Such nutrient loss is called leaching.) On dense clayey soils, overwatering may cause poor drainage, depriving roots of needed oxygen and favoring soil-borne fungal and bacterial diseases. (To appreciate the difference in the depth of water penetration between a clayey and sandy soil, refer to Figure 2-2 in Chapter 2.)
- **Inconsistent watering:** "Feast or famine" watering not only stresses the plants and lowers yield, but may cause physiological problems like blossom end rot in tomatoes and peppers, fruit cracking in tomatoes, splitting heads in cabbage, and bitterness in squash.
- **Watering too late in the day:** This promotes development of damping-off fungal disease in young seedlings by keeping the soil surface moist overnight which helps the fungi proliferate. In older plants, it may favor leaf fungal diseases if the foliage remains wet overnight.

A note on watering in the heat of the day: Contrary to popular belief, hand watering in the full sun at mid-day will seldom injure plants, except in the case of some very tender ornamentals. There is no evidence that water droplets injure leaves by acting like tiny magnifying glasses. However, high soil moisture (after a heavy rain or watering) may sometimes cause a mild "burning" effect (known as sunscald) on the edges of leaves if it occurs in conjunction with high temperatures, intense sunlight, and wind. This is caused by guttation which is the evaporation of excess water from leaf cells, leaving salt deposits behind; these deposits draw water from nearby cells, causing "burning".

Take time to learn the basic principles of watering

There are no quick and easy methods for determining how much water plants need and how often it should be applied. The so called “shiny layer” method popularized in some garden books isn't reliable enough. (With this method, the soil has supposedly received enough water when a shiny layer of water remains on the soil surface for a certain number of seconds after watering stops). You can greatly improve on such “ball park” methods and do much to help farmers, if you'll take the time to learn some fairly straightforward concepts and figures. So, here goes:

HOW WATER IS USED OR LOST

- Actual Plant Usage (called transpiration) is very small when plants are tiny but rapidly increases with plant size and then becomes the main source of water loss. In fact, something like 220-660 liters of water are transpired into the air for every kilogram of dry matter produced.
- Evaporation from the soil surface is the main source of water loss when plants are small and much of the soil surface is unshaded. Still, evaporation losses are much less than transpiration losses of older plants and decrease as plant leaves shade the soil surface more completely.
- Downward drainage through the soil beyond the depth of rooting causes water loss when too much is applied at once. Remember that soils can hold water in their smaller pore spaces (micropores; see Chapter 2) without losing it to drainage (i.e. gravity). Only the water in the larger pore spaces (macropores) isn't held and keeps moving downward.
- Surface runoff usually doesn't amount to much except on sloping soils that lack conservation measures such as contouring.

Factors influencing plant water needs

There are 3 sets of factors that largely determine the frequency and amount of watering that plants need:

Soil Factors: Water-holding capacity and usable depth

Weather Factors: Temperature, wind, humidity, and rainfall

Crop Factors: Type, depth of roots, stage of growth

Let's look at these more closely:

Soil Factors Affecting Plant Water Needs

- A soil's water-holding capacity depends mainly on its texture (see Chapter 2). Compared with clayey soils, sandy soils have more macropores (large pore spaces) which don't retain water as well as micropores. In fact, sandy soils can hold only about half as much usable water per unit of depth as clayey soils which means that:
SANDY SOILS NEED MORE FREQUENT BUT LIGHTER WATERINGS THAN CLAYEY SOILS.

- A soil's humus content also affects its water-holding capacity, but only on sandier soils. Adding compost or manure to clayey soils won't improve their already high water-holding ability. (Humus is partly decomposed organic matter that has become dark and crumbly.)
 - Usable soil depth is another important factor. Shallow soils or those with hardpans or very compacted subsoils that restrict root depth will require lighter and more frequent waterings than usual. Very acid subsoils (below a pH of 5.0-5.5.) can also restrict normal rooting depth.
- Weather Factors Affecting Plant Water Needs

An easy way of understanding this is to realize that any weather condition that speeds up drying your clothes on the line also increases plant water usage. For example:

- Temperature: Plants use more water on hot days, plus evaporation losses from the soil surface are also higher.
 - Sunlight: Plants use more water on sunny days than cloudy days. Unshaded soil will lose more water on sunny days too.
 - Relative humidity: Water use by plants increases as humidity decreases; the same is true with evaporation.
 - Wind: It increases plant water usage as well as evaporation losses.
- NOTE: In some areas such as the Sahel region of Africa, a combination of low humidity, high temperatures and persistent wind is common during much of the dry season and can dramatically increase water needs.

Crop Factors Affecting Plant Water Needs

- Type of Crop: Among field crops, the millets are the most drought-tolerant, followed by grain sorghum and peanuts. Cowpeas, while not as drought-tolerant as sorghum and peanuts, do better than common beans and especially maize when moisture is low.
Among the root crops, manioc (cassava) is very drought-hardy, and sweet potatoes have some resistance. Tropical yams (*Dioscorea* spp.) can tolerate short dry spells, but most types of true taro (*Colocasia* spp.) require high soil moisture. However, the taro-like *Xanthosoma sagittifolium* (tannia, yautia) tolerates drier conditions.

NOTE: In all cases, even drought-resistant crops like millet will yield much less under low moisture. However, non-tolerant crops will often fail.

In general, vegetable crops don't have good drought tolerance, and both yield and quality can be severely affected by moisture stress. However, watermelon and other deep-rooted veggies like okra, eggplant, and tomatoes are more resistant to dry spells than the shallow-rooted veggies like lettuce, onion, and the Crucifer family (cabbage, cauliflower, collards, broccoli, radish, turnip, Brussels sprouts). These shallow-rooted crops need more frequent and lighter waterings than deeper-rooted ones. (See Table 5-1).

- Depth of roots: Aside from differences in final root depth just discussed, all plants will need more frequent and lighter waterings when young. As their roots grow deeper, watering intervals can be spread out and larger amounts applied per application.
- Stage of growth: Plant water needs increase with growth and reach a peak around flowering, fruiting, or heading time. With most veggies, this peak use period continues until harvest time. However, for field crops like maize, sorghum, and dry beans that are harvested at the fully mature, dry stage, water needs taper off as maturity nears.

NOTE: While young plants can often fully recover from a period of moisture stress, a water shortage during flowering, fruiting, or heading can severely affect yield and quality.

TABLE 5-1 Rooting Depth of Crops When There's no Barrier to Penetration

(45-60 cm)
Shallow
(90-120 cm)
Moderately Deep
(More than 120 cm)
Deep
Broccoli Beans Asparagus
Brussels sprouts Beet Bean, lima

Cabbage Carrot Parsnip
 Cauliflower Chard Pumpkin
 Celery Cucumber Field Maize
 Chinese cabbage Eggplant Sorghum
 Garlic Muskmelon (cantaloupe) Squash, winter
 Lettuce Mustard Sugarcane
 Onion Pea, garden Sweetpotato
 Parsley Pepper Tomato
 Potato Rice Watermelon
 Radish Squash, summer
 Spinach Turnip
 Sweet maize

Ok, so get to the point! How much water do plants need and how often?

Well, as you can see by all the variables above, there's no quick answer. BUT, we can give you some definite parameters; you'll need to adjust the figures to suit conditions. First, let's see how much water plants need per week and then deal with how often per week.

Amount Needed per Week

Crop watering recommendations are often given in terms of inches or millimeters (mm) of water per week. One inch (or one mm) of water is equal to filling a flat-bottom tub with 1 inch (or 1 mm) of water. Note that these measurements refer only to the actual thickness of the water layer and say nothing about the size of the tub (or field), nor how deep the water will penetrate in a soil. In terms of actual water volume needed per area, here are some very useful conversions:

1 INCH OF WATER = 7 GALLONS (25 liters) PER SQUARE METER

1 MILLIMETER OF WATER = 1 LITER PER SQUARE METER

TABLE 5-2 TOTAL WEEKLY WATER NEEDS¹
 (Includes both plant usage and evaporation from the soil)

Inches of Water	Millimeters of Water	Liters Needed ² per Sq. Meter
VERY YOUNG PLANTS IN WARM WEATHER		
0.75-1.0"	19-25 mm	19-25 liters
PEAK USE RATES FOR VEGETABLES IN WARM WEATHER (during flowering, fruiting, or heading)		
1.4-2.0"	35-50 mm	35-50 liters ³
PEAK USE RATES FOR FIELD CROPS (from pollination through first 3-4 weeks of grain fill)		
1.75-2.75"	45-70 mm	45-70 liters

*1. If the root zone is very dry, it should be watered before planting to "recharge" it. (See the section on pre-irrigation further along in this chapter.)

*2. Refers to sq. meters of actual planted area. Where the bed-and-alley system is used, only the bed area itself should be watered at these rates; don't water the alleyways, because little or no root growth occurs there.

*3. Severe weather conditions (high heat + hot/dry winds) can increase these rates up to 20% above the maximums given.

How to Use Table 5-2: You'll need to consider weather conditions and crop stage of growth. As a crop grows larger, you'll want to gradually increase the weekly total of water (barring any sudden change in the weather), rather than suddenly increasing it from 25 liters to 45 liters per sq. meter.

Note also that weekly water needs are the same whether a crop is grown on a sandy or a clayey soil. The difference is that clayey soils can tolerate longer intervals between waterings than sandy soils. An exception might be those clayey soils prone to severe cracking when they begin drying out; in this case, considerable extra water could be lost by evaporation from the cracks, unless the soil were mulched or heavily shaded by the crop's leaves. (Heavy additions of sand or organic matter will lessen cracking.)

How Often to Water

There are basically two approaches you can take:

- Lighter, but more frequent waterings.
- Heavier, but less frequent waterings.

Both approaches will satisfy crop water needs, as long as the total amount applied per week is adequate. (Refer to the water dosage table above.) Both methods will achieve the same depth of water penetration, given equal amounts of water per week. It's possible that frequent watering may result in somewhat higher evaporation losses on unmulched (or unshaded) soils; on the other hand, frequent watering may help prevent soil cracking on certain clayey soils, thus reducing evaporation losses.

In deciding which of the approaches to take, you'll need to consider 4 factors: soil waterholding capacity, root depth, water supply, and labor considerations.

- Soil water-holding capacity: Sandy soils need more frequent (about twice as often) but lighter waterings than clayey soils, because they can hold only about half as much usable water per unit of depth.
- Root depth: The shallower the root system, the more often watering is needed. Young plants need more frequent watering, because their roots are shallow and the water around them more quickly exhausted. Naturally shallow-rooted crops like lettuce and cabbage need more frequent watering than deeper-rooted crops like eggplant and tomato.

NOTE: During the first few days following transplanting, seedlings will often need more frequent watering than their size would indicate. In hot weather, twice-daily watering may be needed for up to a week after setting. Seedlings that have been container-grown suffer less root damage during transplanting and are less susceptible to drying out. Likewise, proper hardening by restricting watering for 7-10 days prior to setting out the seedlings will lessen initial water needs.

- Water supply: If you're hand-watering from a well that has a limited daily output, it may be necessary to make light applications once or twice a day instead of heavier, less frequent ones which might exhaust a hand-dug well's daily capacity. (An alternative would be to water only a portion of the garden each day.). Farmers using furrow-irrigation from a cooperative system may receive water only once every several days.

- Labor considerations: In some cases, farmers/gardeners will prefer to even out the watering labor by watering as often as once or twice a day (using light applications), even though crop/soil factors might allow one heavier watering every 2-4 days or more.

How often to water before seedling emergence: Most seeds must be surrounded by constantly moist soil to be able to sprout. Large seeds such as maize and beans can usually be planted deep enough so that they will require no additional water after planting in order to sprout. However, most smaller seeds, especially the tiny ones like such as lettuce and amaranth, need to be

planted very shallow (5-15 mm). In this case, the soil surface should be kept continually moist until seedling emergence. Unless a pre-emergence mulch is used, this may require watering up to 3 times a day on sandy soils in hot, sunny weather. (Pre-emergence mulching is explained in Chapter 8).

Some Practical Examples of Watering Frequency

NOTE: These examples are designed to calculate the minimum allowable frequency per week; it's OK to water once or twice a day, as long as the liters per application are reduced proportionally so the same total is applied per week.

EXAMPLE 1: Suppose you're growing cabbages on a clayey soil in warm weather, and they're at the heading stage. You figure that 40 liters per sq. meter are needed weekly. Clayey soil has a good water-holding capacity, but cabbage is shallow-rooted, so you'll probably need 2 waterings a week of 20 liters per sq. meter each.

EXAMPLE 2: Now let's substitute tomatoes at the flowering/fruitleting stage in the above example. Unlike cabbages, they're a deep-rooted crop (barring no barriers to root penetration). Supposing that 50 liters/sq. meter are needed weekly, you could probably water them once every 5 days. Here's how you'd calculate the amount needed per watering:

50 liters/sq. meter per week needed

$\frac{5}{7} \times 50 \text{ liters} = \text{about } 36 \text{ liters/sq. meter every 5 days}$

EXAMPLE 3: Now let's take a nursery seedbed with young tomatoes, peppers, and cabbage on a very sandy soil in warm weather. Weekly water needs will be about 20-25 liters/sq. m. You'd probably have to water once or twice a day during the first week after seedling emergence, applying 3-3.5 liters/sq. m daily. Obviously, if you put on the entire 20-25 liters/sq. m all at once, most of the water would end up beyond the root zone and be wasted. By the time the plants are 1-2 weeks old, you could probably reduce the frequency to once every 2 days.

All the above examples are only approximations; you'll have to decide the amount and frequency that best suits the situation.

How to Tell When Plants Need Water

Initial signs of moisture stress: Wilting, leaf curling (or rolling), and, in some cases, color changes (maize and other plants will often turn bluish-green).

Advanced symptoms of moisture stress Yellowing and eventual browning ("firing") of the leaves, starting at the tips.

NOTE: Most of these symptoms can also be caused by anything else that interferes with water uptake or transport such as nematodes, soil insects, stem borers, fungal and bacterial wilts, fertilizer burn, and even high temperatures. N deficiency can cause yellowing too.

Ideally, plants should never be allowed to reach the advanced stages of moisture stress between waterings. A little wilting won't affect young plants, but even a day of it can lower yields and quality of crops at the flowering, fruiting, and heading stage.

Two Tests to Determine if Watering is Needed

- The "Scratch" Test can be used on young seedlings when their roots are shallow. Scratch

into the soil with your finger and see how far down you have to go to reach moist soil. If the soil is dry more than 2-3 cm down, it may be time to water shallow rooted seedlings.

- The “Squeeze” Test: Using the table in Appendix B, you can estimate the percentage of available water left in the root zone. Water should usually be applied before half of the root zone’s available water has been used up. Plants take up about 40 percent of their water needs from the top quarter of the root zone. Once this top quarter gets down to 0 percent available moisture, it’s time to apply more.

Measuring how deep water has penetrated: Use a 10-12 mm (about 0.5”) diameter steel rod slightly tapered at end. Wait about 12-24 hours after watering and then push the tapered end into the ground. It should penetrate fairly easily until it strikes dry soil. (Hardpans may affect the accuracy of this method.)

Figuring in Rainfall

Since rainfall will affect the need for watering, it’s important to record it. Buy a rain gauge or make one out of a tin can with straight sides. Amounts below 6 mm (1/4 inch) aren’t much use to plants, because a lot may be lost to evaporation. Likewise, heavy downpours may result in much wasted runoff or loss from downward drainage beyond the root zone. For example, a 100 mm (4”) rainfall may only add the useful equivalent of 20-30 liters/sq. meter for a shallow-rooted crop like cabbage on a sandy soil. (Remember that each millimeter of rainfall is equal to 1 liter of water per sq. meter.)

What about Pre-Irrigation?

It’s often advisable to pre-irrigate the soil down to eventual rooting depth before planting, especially if the root zone is very dry. Use the chart in Appendix B to determine the moisture status of the soil. Then use the water-holding capacity chart in Chapter 2 to determine how much pre-irrigation is needed. If the proper amount of water is applied, little will be lost except the small amount that will evaporate from the soil surface and the first few centimeters. The rest will be safely held in the micropores for future use. (Clayey soils prone to cracking while drying out may have higher evaporation losses). Pre-irrigation also has some other possible benefits:

- Improving filth (workability) of very clayey soils: Very hard, dry, clayey soils can be much more easily worked if given a good soaking (at least 25 liters/sq. meter 1-2 days before land preparation).
- Pre-planting weed control in vegetable plots: Watering a prepared vegetable bed 7-10 days before planting will encourage many weed seeds to sprout. A very shallow weeding with a sharp hoe blade (using a scraping action) will kilt these weeds without moving more weed seeds closer to the soil surface where they can more easily germinate. This can substantially reduce weed problems on soils with high populations of annual weeds (i.e. those that reproduce by seed).

Some methods for improving water use efficiency

In much of the Third World, water is scarce during the dry season, yet irrigated crop production requires tremendous quantities. Below are some suggestions for helping farmers use water more efficiently. While each of them will help conserve water, using several of these methods together will be the most effective.

- Draw up a watering quantity and frequency schedule tailored to the specific soil, weather, and crop. Remember to consider the water supply and labor factors mentioned above. For example, it might be possible to water older tomatoes just once every 4-5 days on a clayey soil, yet the well may not be able to supply the large quantity needed all at once.
- Use the bed-and-alley system for small scale vegetable production (see Chapter 4). By allowing much closer spacing of plants and reducing soil compaction, it usually results in higher yields than using a conventional wide-row spacing system. The higher plant populations and yields per sq. meter of bed actually require little or no extra water, because the closely

spaced plants shade the soil surface more effectively, thus acting as a living mulch. Due to higher yields, water needs per kg of production are usually much less.

- Use windbreaks where hot, drying winds are a problem. They'll cut down water losses from evapo-transpiration as well as protect from wind damage itself. Staggered rows of fast-growing trees around the windward portion of a garden can be very effective and also provide fruit, animal feed, and firewood. (Refer to Chapter 3 for further details on windbreaks.)
- Mulching the soil surface with peanut hulls, rice hulls, straw, or dried grass will greatly reduce water evaporation losses. Mulching has several other benefits (see Chapter 8) but may attract crickets, ants, termites, slugs, and other harmful insects. Consider both pre-emergence and post-emergence mulching.
- Choice of seedbed: Raised beds (if not mulched) dry out more quickly than sunken or flat beds. Under very dry conditions, sunken beds are usually the best choice, especially since they prevent water from running off. (See Chapter 4 for seedbed styles).
- Microcatchments are shallow "bowls" from about 30 cm to several meters in diameter made in the soil with a plant or tree placed in the center. They are very effective at collecting water from the surrounding area and concentrating it around the roots. In rainy conditions, however, they may promote poor drainage and encourage soil-borne diseases.
- Various kinds of macrocatchments can be used which collect water from larger areas that have moderate slopes. One technique is contour damming where soil barriers are run across the slope to collect water runoff.
- Soil conservation measures like contouring and terracing will markedly improve water retention by lessening runoff from rainfall or watering. See Chapter 3.
- Rainwater can be collected off roofs and used for gardening. Each sq. meter of roof will provide 1 liter of water per 1 mm of rainfall.
- Good weed control will also reduce water losses, because weeds can use up considerable amounts of water.
- Where soils are very clayey and compacted, double-digging the plots and adding organic matter to the subsoil will improve rooting depth and allow greater intervals between watering. (See Chapter 4).
- Adding compost or manure to sandy soils will increase their water-holding capacity.
- Use partial shade on less heat tolerant crops like lettuce and the Crucifer family (cabbage, broccoli, cauliflower, etc.).
- The "double transplant" ("double nursery") method of raising veggie transplants is worth trying. When transplants are big enough to be set in the field, they are instead transplanted to a larger nursery seedbed where they can be spaced about 15 cm apart. This allows them to be kept in a confined area much longer, thus saving water as well as labor. This method works well with tomatoes, since they have good tolerance to delayed field-setting. (They should be "deep set" when transplanted so that most of the stem is buried underground where it will generate new roots; most other vegies lack this ability.)
- Choose drought-resistant varieties: This applies more to field crops like maize where more work has been done on selection and breeding for drought resistance. For example, even though maize isn't very drought tolerant, there is considerable variation among varieties. However, choosing drought tolerance at the expense of needed disease resistance or other desirable traits may not be a good tradeoff.

- Balanced fertilization, whether chemical or organic, helps improve water use efficiency by stimulating more extensive root growth. Note, however, that crops can't utilize as much fertilizer when moisture is limiting.
- Soil nematode control: When present, root-feeding nematodes can seriously inhibit water (and fertilizer) uptake by plant roots.
- Drip irrigation is a method of supplying water to plants by running small diameter plastic tubing down the row. Porous tubing (trickle tubing) is used for closely-spaced crops like carrots; for crops wider-spaced crops such as tomatoes, small individual emitters are used to concentrate the water around the plants. Water is provided at low volume and pressure, and plants are watered about once every day or two. Drip irrigation can save water by delivering it close to the plants and by reducing water runoff and the amount of wetted soil surface prone to evaporation. However, water use efficiency is highest when the system is used with widely-spaced plants like tomatoes and squash since less area needs to be wetted. Drip irrigation is relatively inexpensive and, except for the micro-tubing, most components can be fabricated from in-country materials. Fertilizer can also be distributed through the system, though special soluble types are needed. The main problem with drip irrigation is its tendency to clog, even when filtering is used. Improved tubing and emitter designs have overcome this problem somewhat. With care, the microtubing may be used for several seasons.

Part II: Soil fertility management

Chapter 6: Soil fertility and plant nutrition simplified

A Practical Approach

For many farmers and development workers, soil fertility management is one of the more mysterious aspects of crop production. How and when do you apply fertilizers? What kind and how much? What about chemical vs. organic fertilizers? Part II of this manual will cover all of these concerns.

Let's make a deal

Soil fertility may not seem like a very stimulating topic, and you may not feel like reading over 100 pages on it. But, look at it this way. Soil fertility management is a vital part of successful crop production, yet an area that's often misunderstood and prone to faulty management. If you're willing to read through Part II and learn to use it as a field reference, you'll know at least as much about the practical aspects of soil fertility as most agronomists. But more important, you'll be a more effective ag extension worker in terms of your knowledge; you'll also find that many of these principles can be readily understood and applied by farmers who have little or no formal education. After all, one goal of true development work is to "empower" the poor, to give them more control over their circumstances. Knowledge of this sort is a step in the right direction.

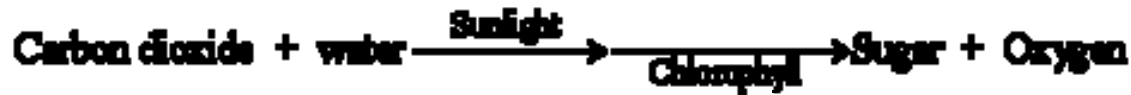
Before covering how to use organic and chemical fertilizers, there are some very useful soil fertility fundamentals we should go over. That's the purpose of this chapter.

How plants grow

Plants grow by enlarging their cells and by developing new ones at their shoot and root tips.

Photosynthesis: How Plants Make Food and Tissue

Plants produce food for energy, tissue building, and storage by a process called photosynthesis which takes place in the green, chlorophyll-containing cells found mainly in the leaves. These cells take carbon dioxide from the air and combine it with water (taken in by the roots) to make simple sugars, using chlorophyll and sunlight as catalysts. As shown below, oxygen is also a byproduct:



This sugar is the real “food” of plants, and here's what they do with it:

- It's used for energy in a process called respiration in which the plant digests it much like we do and releases carbon dioxide.
 - Sugar is also stored “as is” in varying amounts (i.e. maize contains a small amount, but sugarcane has a lot).
 - It's used to make cellulose and other types of fiber that hold cells and plants together. Plants are the only source of fiber in our diets.
 - Sugar can be converted to starch, the main component of most seeds and other starchy crops such as bananas, potatoes, cassava (manioc), and other root crops. It is also converted into fat, a principal constituent of some crops such as coconut, soybeans, peanuts, and avocados.
 - Sugar, when combined with nitrogen, forms protein.
- Photosynthesis governs the rate of plant growth and is the biggest factor affecting crop yields. It's encouraged by:

- Adequate sunlight. Cloudy weather lowers the rate of photosynthesis.
- Adequate moisture.
- Favorable temperatures, which vary with the type of plant.
- Adequate mineral nutrients like nitrogen, phosphorus, etc.
- Good insect and disease control which prevents the destruction of green tissue.
- Adequate carbon dioxide. Normal air contains enough. Some greenhouse growers try to raise the level.

A Note on “C4” Plants: Some crops such as maize, sorghum, amaranth, and sugarcane have an unusually efficient type of photosynthesis that functions best under high temperatures, full sun, and low-humidity conditions. They're called C4 plants.

So Where Do the Plant Nutrients Fit In?

The plant mineral nutrients like nitrogen are supplied by the soil and supplements of fertilizer. They are absorbed by the root hairs (tiny, delicate protrusions on the roots) in the form of ions (molecules with a + or - charge) from the soil water and perform many functions. Some, like potassium, are used in sugar and starch formation, while nitrogen is used for making protein and chlorophyll.

Available vs. unavailable forms of mineral nutrients

Aside from water and carbon dioxide, plants need about 14 mineral nutrients: NITROGEN, PHOSPHORUS, POTASSIUM, CALCIUM, MAGNESIUM, SULFUR, IRON, MANGANESE, COPPER, ZINC, BORON, MOLYBDENUM, SODIUM and CHLORINE (these last two are rarely deficient).

Each of these mineral nutrients occurs in both available and unavailable forms in the soil. For instance, only about 1-2% of a soil's potassium is actually available to roots; most of the other 98.99% is tied up as part of rock fragments or clay particles and is very slowly released over time.

Likewise, only about 1-2% of a soil's nitrogen is readily usable by plants. The rest is in the organic form as dead leaves, roots, and crop residues in various states of decomposition; organic nitrogen doesn't become usable until soil bacteria have converted it into ammonium or nitrate ions.

The same applies for each of the other nutrients to varying degrees, depending on soil conditions. As we'll see, soil pH can have a big effect on nutrient availability.

Soil negative charge and nutrient holding ability

Some soils have much higher leaching losses than others. (Leaching occurs when downward-moving water carries nutrients with it out of the root zone).

Factors Affecting Leaching Losses

Soil texture, negative charge, and amount of rainfall or watering determine a soil's leaching potential:

- Sandy soils are very susceptible to leaching losses for 2 reasons. First, they tend to have a low negative charge, which means little ability to hold on to plus-charged nutrients. Second, a given amount of water will penetrate more deeply than on finer textured soils with higher water-holding capacity (see Chapter 2).
- Clayey soils and those high in humus have lower leaching losses, due to higher negative charge and better water-holding capacity (up to twice as much as sandy soils. Remember, however, that "tropical" clays (e.g. kaolin and hydrous oxide clays) have a very low negative charge.
- The higher the rainfall, the higher the leaching losses.
- The "worst-case" scenario for leaching would be a sandy soil low in humus, under high rainfall.

How Negative Charge Helps a Soil Hold Nutrients

Clay and humus particles have a negative charge. The available forms of plant nutrients exist as ions which are molecules with a positive (plus or +) charge or negative (minus or -) charge. The minus-charged clay and humus particles act like little magnets to attract and hold those plus-charged ions like potassium (K^+), calcium (Ca^{++}), and magnesium (Mg^{++}), which gives them some resistance to leaching. The nice thing is that the plus-charged ions (called cations) are available to roots even when held by the clay and humus particles. Cations will still leach somewhat, but not nearly as much as the anions.

Unfortunately, the minus-charged nutrient anions like nitrate (NO_3^-) and sulfate (SO_4^{--}) aren't so lucky. Since like charges repel, they're not held by the minus-charged clay and humus particles; instead, they end up floating around freely in the soil water, which makes them very prone to leaching in most cases.

TABLE 6-1

Some Common Plant Nutrients and Their Susceptibility to Leaching

- + Charged Nutrients (Cations)
(fairly resistant to leaching)
- Charged Nutrients (Anions)
(easily lost by leaching)

Ammonium nitrogen (NH_4^+) Nitrate nitrogen (NO_3)

Potassium (K^+) Sulfate (SO_4)

Calcium (Ca^{++}) (Mg^{++}) NOTE: Leaching losses of potassium can be a problem on sandy soils under high Magnesium rainfall.

What about Phosphorus?: It's an exception. Even though its 2 soil ionic forms (H_2PO_4^- , HPO_4^{--}) have a minus charge, they hardly move at all in the soil, because they readily form insoluble, immobile compounds with iron, aluminum, calcium, and magnesium. While this keeps phosphorus from leaching, roots have trouble absorbing it in this form. This "tie-up" is called phosphorus fixation and can be a serious problem on many soils, especially when phosphorus fertilizers aren't applied correctly.

NOTE: Don't confuse phosphorus fixation with nitrogen fixation (the process by which rhizobia bacteria associated with legumes convert atmospheric N into usable form for these plants).

How Soil Negative Charge is Measured: Cation Exchange Capacity (C.E.C.)

The exchange capacity of a soil (also called cation exchange capacity or C.E.C.) is a measure of its negative charge or the amount of plus-charged nutrients it can hold against leaching.

A soil's C.E.C. depends on its clay and humus content, since they're the only 2 soil particles with a minus charge. Soils with a low C.E.C. are especially prone to leaching and have poor nutrient-retaining ability. Even soils of the same texture can vary markedly in C.E.C. due to variations in humus content and the type of clay minerals they contain (see Table 6-3).

Table 6-2 illustrates the marked variations in C.E.C. between humus and clay, as well as among different types of clay. Note the very high charge of humus, which is why it can easily account for the major portion of the C.E.C. in many soils, even when present at typical normal levels of just 24% (by weight). These differences explain why C.E.C. varies so much among soils (even those of the same texture), as shown in Table 6-3.

TABLE 6-2

The Relative Cation Exchange Capacity of Clay and Humus Particles

C.E.C.*

Humus 150-200

"Temperate" -type clay minerals 15-100

"Tropical" -type 2-15
clay minerals

TABLE 6-3 Typical Variations in Cation Exchange Capacity among Soils

Soil Name C.E.C. of the Topsoil*

Hilo clay (Hawaii) 67

Cecil clay (Alabama) 4.8

Susquehanna clay (Alabama) 34.2

Greenville sandy loam (Alabama) 2.3

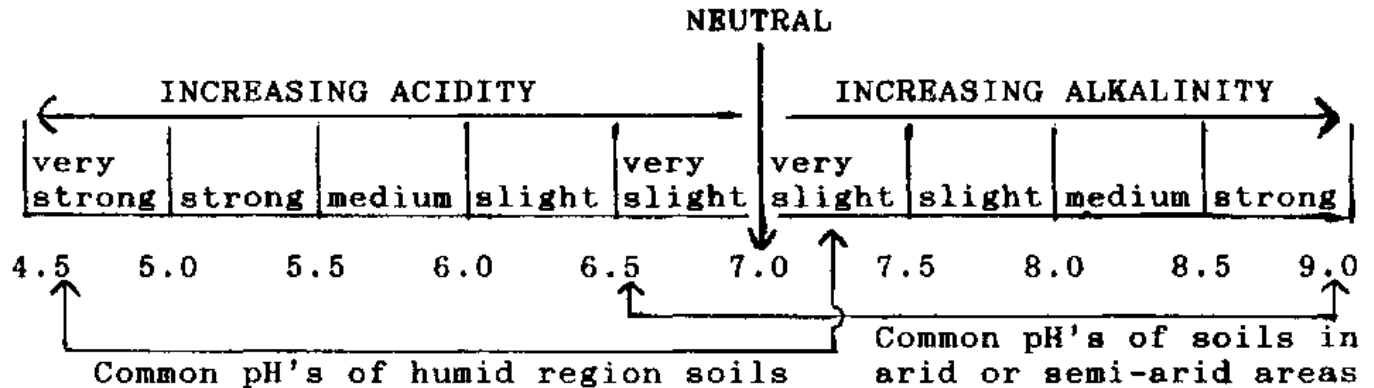
Colma sandy loam (California) 17.1

*Don't worry about what the actual numbers mean; it's the comparison that counts. (If you're familiar with chemistry, C.E.C. is measured in terms of milliequivalents of cations per 100 grams of soil.)

Soil pH and how it affects crops growth

Soils can be acid, neutral, or basic (alkaline), and this is measured in pH units. The pH scale runs from 1 (maximum acidity) to 14 (maximum alkalinity) with 7 being neutral. Most soils fall in the range of 5.0-7.5 with extremes from 4.0-9.0 as shown in Figure 6-1.

FIGURE 6-1 pH Ranges of Soils



Acidity is caused by hydrogen ions (H^+), and alkalinity by hydroxyl ions (OH^-). A pH of 7.0 is neutral, meaning that there are equal numbers of H^+ and OH^- ions. As pH drops below 7.0, the H^+ ions begin to outnumber the OH^- ions, and acidity increases.

The pH scale is logarithmic: This means that a soil with a pH of 4.0 is 10 times more acid than one with a pH of 5.0, and 100 times more acid than one with a pH of 6.0. A pH of 3.9 is 1000 times more acid than a pH of 6.9. Likewise, a pH of 8.5 is 10 times more alkaline than a pH of 7.5 but 10 times less alkaline than a pH of 9.5.

Why Does pH Vary so Much Among Soils?

Climate, amount of leaching, parent material, and farming practices all affect soil pH:

- **Climate and Leaching:** As illustrated by Figure 6-1, soils of high-rainfall regions are likely to be on the acid side. That's because a good deal of calcium and magnesium (the main bases in the soil) have been leached away by rainfall. It's a slow process since they're both plus-charged ions, and here's how it works. Acid-forming H^+ ions are produced by the breakdown of organic matter and acid parent rocks like granite, and also by using most chemical fertilizers containing nitrogen. Being cations, too, these H^+ ions can "bump" some of the adhered calcium and magnesium ions off the clay and humus particles and take their places. Once back in the soil water, the Ca and Mg are prone to leaching. Where rainfall is high, this results in more acid soils.

In contrast, soils of drier regions like the Sahel are more likely to be alkaline or only slightly acid, because less leaching of Ca and Mg occurs where rainfall is lower.

Soils of drier regions aren't always alkaline, nor are soils of wet regions always acidic. Parent rock and farming practices also have an influence.

- **Parent Rock:** Soils formed from basic rocks like limestone and basalt tend to be less acidic (or more basic) than those developed from acidic rocks like granite and sandstone. However, even soils formed from limestone may be somewhat acidic if leaching has been intense.
- **Farming practices:** Liming the soil will lessen acidity (raise pH). Manure, compost, and most chemical fertilizers containing nitrogen will gradually increase soil acidity when used over the years.

Why Worry about Soil pH Anyway?

Soil pH can have a big effect on crop growth and yields. Most crops will produce satisfactory

yields within a pH range of about 5.5-7.5, with a pH of about 6.3 being ideal for most. Some crops like pineapple, coffee, potatoes, and sweet potatoes are especially tolerant of soil acidity. (For more information on crop tolerance, see Table 11-1 in Chapter 11.)

How Soil pH Affects Crop Growth

- The tie-up (fixation) of phosphorus is greatly affected by soil pH. Phosphorus is most available within a pH range of 6.0-7.0. (See Chapter 11.)
- Very acid soils can be toxic to plants. Aluminum, manganese, and iron become more soluble as soil acidity increases and can actually injure plant roots at pH's below 5.0-5.5, depending on the soil and type of plant.

- Soil pH affects the availability of micronutrients to plant roots. Except for molybdenum, the other 5 micronutrients (iron, manganese, copper, zinc, boron) become increasingly available to plants as acidity decreases (i.e. as pH rises). Iron and manganese are the most affected and may become so insoluble at pH's above 6.5 that plants can suffer deficiencies (see Figure 62).
 - Most beneficial soil microbes can't thrive in very acid soils. (Beneficial soil bacteria and fungi are described in Chapter 1).
 - Salinity and alkalinity problems occur at pH's of 8.0 and above where sodium and other salts are present at levels high enough to be toxic to plants (see Chapter 12).
- <<l>> p101.jpg FIGURE 6-2: Influence of soil pH on plant nutrient availability in mineral soils. Widest parts of the shaded areas indicate maximum availability of each nutrient.

How can You Measure Soil pH?

Soils labs determine pH as a routine part of soil testing. You can also make fairly accurate readings right in field with a liquid indicator kit or portable electric tester. See Chapter 11 on liming for details.

How Can You Change Soil pH?

Liming will lessen soil acidity and raise the pH. Some common liming materials are limestone (calcium carbonate), dolomitic limestone (a mixture of calcium and magnesium carbonates), and burned lime (calcium oxide). Sulfur and aluminum sulfate can be used to further lower the pH of acid soils "sometimes done for acid-robing crops like blueberries). Gypsum (calcium sulfate or chalk) has no effect as a liming material but can be used to remove sodium (a powerful base) from very alkaline soils, thus lowering the pH toward neutral.

For more information on changing soil pH, see Chapter 11 on liming and Chapter 12 on salinity and alkalinity problems.

Important facts on the plant nutrients

The plant mineral nutrients can be grouped into 2 classes: MACRONUTRIENTS and MICRONUTRIENTS.

MACRONUTRIENTS

Primary Macronutrients Secondary Macronutrients

NITROGEN (N) CALCIUM (Ca)

PHOSPHORUS (P) MAGNESIUM (Mg)

POTASSIUM (K) SULFUR (S)

MICRONUTRIENTS

IRON (Fe) ZINC (Zn)

MANGANESE (Mn) BORON (B)

COPPER (Cu) MOLYBDENUM (Mo)

Macronutrients vs. micronutrients

The 6 macronutrients make up about 99% of a plant's diet. N, P, and K account for about 60% and are definitely the "BIG 3" of soil fertility in terms of quantity needed and likelihood of deficiencies.

TABLE 6-4

Amount of Nutrients Needed to Produce 4000 kg of Shelled Maize

Macronutrients Kg	Micronutrients Kg
Nitrogen 112	Iron 3.0
Phosphorus (P ₂ O ₅) 43	Manganese 0.7
Potassium (K ₂ O) 89	Zinc 0.2
Calcium 21	Copper 0.05
Magnesium 18	Boron 0.05
Sulfur 17	Molybdenum 0.0054

This doesn't mean that the secondary macronutrients or the micronutrients are any less essential. Although their deficiencies usually aren't as common, they can have just as serious an effect on crop yields when they occur.

The "Big 3": N, P, and K

NITROGEN (N)

Role of Nitrogen

N is the most commonly deficient nutrient in most cultivated soils. It plays several important roles:

- It's an essential part of chlorophyll, needed for photosynthesis.
- Plants combine N with sugars to make protein. All protein contains about 16% N.
- It promotes vegetative growth (leafy growth).
- It promotes plumpness of grain kernels.

Crops Vary in their N Needs

Crops with High N Needs

- Crops making lots of vegetative growth have high N needs, as long as there's sufficient water for high yields.
 - Cereals, leafy vegetables (lettuce, cabbage, etc.), fruit-type vegetables (tomatoes, peppers, etc.), pasture grasses, sugarcane, and bananas. However, most of the traditional, taller-growing varieties of rice and wheat are likely to lodge (tip over) at high N rates.
 - Legume crops also have high N needs but are a special case because of their N-fixing ability.
- Crops with Moderate N Needs

- Most root crops such as turnips, beets, carrots, tropical yams, potatoes, sweet potatoes, cassava (manioc), and taro have lower N needs than those above. Too much N may favor leaf production over tuber growth. However, some of the newer potato cultivars (varieties) respond well to high levels of N.

What about the N Needs of Legumes?

Legumes are partly to wholly self-sufficient in meeting their own N needs due to their symbiotic relationship with rhizobia bacteria (*Rhizobium* sp.) that live in nodules on their roots. The rhizobia convert the unavailable nitrogen in the soil air to a usable form for the plant; this process is called nitrogen fixation. As explained below, legume. vary in their N-fixing ability. (For more information on N fixation, refer to the section on pulses in Chapter 10.):

- Some pulses “legumes producing edible seeds), such as soybeans, cowpeas, peanuts, mungbeans, pigeonpeas, winged beans, and vining (tropical) types of lima beans, can meet all their own N needs if the right strain of rhizobia is present.
- Field beans (navy beans, black beans, kidney beans, pinto beans; botanical name = *Phaseolus vulgaris*), field peas (*Pisum arvense*), garden peas (*Pisum sativum*), and the bushy varieties of lima beans have less efficient types of rhizobia and can meet only about half their N needs through fixation.
- Pasture legumes, such as clovers, tropical kudzu, and stylo, are wholly self-sufficient and can even produce enough extra N to satisfy the needs of any pasture grass that might be intermixed with them.

The Effects of too Much N

Too much N may have an adverse effect on crop growth, especially if other nutrients are deficient. It may:

- Delay maturity, though not always.
- Lower disease resistance by making growth overly succulent and more easily penetrated by disease organisms.
- Discourage tuber or fruit formation in favor of vegetative growth.
- Increase lodging (tipping over of stems), especially in the traditional, taller-growing varieties of rice and wheat.

HOW NITROGEN BEHAVES IN THE SOIL

Available vs. Unavailable Forms of N

Only about 1-2 percent of a soil's native N is actually available to plants and exists in the inorganic (mineral) form as ammonium (NH_4^+) or nitrate (NO_3^-). The other 98-99 percent is bound up in the unavailable organic form as part of humus or crop residues which soil microbes gradually convert to ammonium and nitrate (see Fig. 6-3). Most soils are too low in organic matter to supply available N at a rapid enough rate, so that's why N fertilizer (organic or chemical) is needed.

FIGURE 6-3: Soil microbes convert organic N to available forms.

(Unavailable)	(Available)	(Available)
ORGANIC N	Ø AMMONIUM N (NH_4^+)	Ø NITRATE N (NO_3^-)
(weeks, months)	(days, weeks)	

Available N can be Easily Lost by Leaching

The ammonium (NH_4^+) form of N has fairly good resistance to leaching (except on low C.E.C. soils) because of its plus charge. However, nitrate N (NO_3^-) is more readily leached because of its minus charge.

Lowering leaching losses: If using chemical fertilizers, you might think that leaching could be avoided by choosing the ammonium form of N. The problem is that, in warm soils, soil bacteria will convert nearly all the ammonium into leachable nitrate in just 7-10 days! In cooler soils, the conversion is much less rapid. For example, if soil temperature averages 11°C (52°F), only about 50 percent of the ammonium will be converted to leachable nitrate in 5 weeks. In fact, farmers in the U.S. Corn Belt can apply ammonium N fertilizers in the fall (5-6 months before planting) with little or no leaching losses, thanks to very low winter soil temperatures.

Under warm conditions, the most practical way to reduce leaching losses is to “spoon feed” N when its applied as a chemical fertilizer or to use organic sources like compost and well-rotted manure which are slow-release sources of available N (organic N does not leach). This is covered in Chapters 8 and 9.

Denitrification: Another Way that N is Lost

In poorly-drained soils where there's little air, much available N can be lost by denitrification. What happens is that certain kinds of anaerobic bacteria (those that can function without oxygen) convert any nitrate (NO_3^-) into nitrogen gas which escapes out of the soil and is lost. Losses can be very high if the soil is flooded for even a day or two after a heavy rain.

Even soils that appear well-drained at the surface may have serious denitrification losses taking place in the subsoil if it's poorly drained. Improving drainage is the best way to control these losses (see Chapter 2). Flooded rice soils require special fertilizer management to avoid large denitrification losses of N. (See Chapter 10.)

Temporary N Tie-up by Crop Residues

Available soil N can become temporarily tied up by bacteria if crop residues or organic conditioners like rice hulls are worked into the soil. Below is an explanation of this type of N tie-up and how to prevent it:

- The soil bacteria that decompose crop residues use carbon for energy and nitrogen to make protein for growth and multiplication. Most non-legume residues such as maize stalks have plenty of carbon but too little N. Rice hulls, peanuts hulls, millet hulls, and sawdust even less.
- The bacteria make up for the shortage of N in their “food” by borrowing nitrate N from the soil itself. A crop growing in such a soil may suffer a temporary N deficiency until the bacteria have completed most of the initial “digesting”. As the residues are converted to humus, bacterial activity, decreases and the “borrowed” N again becomes available as many bacteria die off. The temporary N deficiency may last several weeks.
- NOTE: Stalk and leaf residues of legumes like beans, cowpeas, and peanuts are usually high enough in N to avoid these tie-up problems. However, peanut hulls (shells) are low in N. This type of N tie-up can be prevented in 3 ways:

- If possible, turn under low-N residues at least a month before planting to give them time to rot. However, little decomposition will occur if the soil is dry or very cold.
- At planting time, be sure to add enough N (either from chemical fertilizer or from an organic source high in readily available N such as fresh manure) to sustain the crop during the tie-up period. This will take roughly 30-60 kg/ha of actual N or the equivalent of 75-150 kg/ha of urea fertilizer (45-0-0). The fertilizer doesn't have to be mixed into the entire soil area, either. In fact, less N is needed if it's placed near the crop row where the plants have good access to it.
- The residues can be collected and composted before returning them to the field. This is done in parts of S.E. Asia with rice straw residue but is laborious and requires the addition of high-N materials such as fresh manure to encourage the breakdown of the low-N straw. (For more information on composting, refer to Chapter 8.)

PHOSPHORUS (P)

Role of Phosphorus

Phosphorus plays many roles in plant growth and exerts a beneficial effect on:

- Root formation and early growth.
- Flowering, fruiting, and seed formation.
- Crop quality, especially in vegetables and forage crops.
- Resistance to some diseases.

Phosphorus Deficiencies are Widespread

As with N, most soils are deficient in P for several reasons:

- Most soils are low in total P.
- Much of a soil's natural P is tied up and unavailable to plants.
- Much of the P applied in chemical fertilizer form can become tied up also.

Phosphorus Tie-up (Fixation)

- Only about 5-20 percent of the P you apply as chemical fertilizer to an annual crop like maize or vegetables will actually be available to it. In acid soils, much of the P gets "fixed" (tied up) by reacting with iron, aluminum, and manganese to form insoluble compounds. In basic soils, the added P has a similar reaction with calcium and magnesium.
- The amount of P immediately available from an application of chemical fertilizer depends on the amount applied but even more so on the application method used.
- Some of the 80-95 percent of the P that becomes "fixed" will eventually become available again to crops over the years. There's a saying that applying fertilizer P is like putting money in the bank and living off the interest. The amount of future interest you get depends a lot on the type of soil. Some soils, especially very acid, red soils high in "tropical" clays, can have an extraordinary P fixation ability and may tie up 95-99 percent applied fertilizer P in a virtually irreversible, unavailable form.
- The P in organic fertilizers like compost and manure is much less subject to fixation.

NOTE: Don't confuse P fixation with N fixation!

- Temporary P tie-up by decomposing crop residues: As with N, some soil P can become temporarily tied up when low-nitrogen crop residues (i.e. those from non-legumes) are worked into the soil. The bacteria that break down the residues need P as well as N for their growth and multiplication and end up borrowing both from the soil as explained in the previous section on nitrogen. Such tie-up can last for several weeks or more, but can be compensated for by applying P fertilizer near the row. Legume residues break down quickly enough so that tie-up isn't a problem.

How to Minimize P Tie-up Problems

- Application method is vitally important: In most cases, chemical fertilizer P should not be broadcast (spread) but applied in a band, hole or half-circle to concentrate it near the plant row. (Refer to Chapter 9.)
- Maintain a good level of soil organic matter: Decaying organic matter produces humus and organic acids that form complexes with iron and aluminum; this can considerably reduce their ability to tie up P.
- Lime overly acid soils: P fixation problems are more serious at very low pH's. Likewise, pH's above 7.5 increase P tie-up too. P is most available within a pH range of 6.0-7.0.
- N helps encourage the plant's uptake of P, so applying N and P at the same time is helpful (if N is needed).

Some Good News: P Doesn't Leach!

Unlike nitrate N, P is pretty immobile in the soil, and leaching losses are virtually nil, even on

sandy soils. This means there's no need to "spoonfeed" fertilizer P by splitting the dosage into two or more applications; all can be applied at transplanting or planting.

POTASSIUM (K)

Role of Potassium

- It promotes starch and sugar formation. Crops such as bananas, sugarcane, and starchy root crops like potatoes, cassava, and taro have especially high needs.
- It favors root growth, stalk strength, disease resistance, and general plant vigor.

K Deficiencies are Less Common

- Unlike N and P, deficiencies of K are less likely, but don't automatically assume that K isn't somewhat deficient in your area.
- Soils of volcanic origin tend to be especially high in K.

Relative K Needs of Crops

- Starch and sugar crops have the highest requirements.
- Cereal crops and other grasses have a better ability to extract K from the soil than broadleaf plants.

"Luxury Consumption" of K

If high rates of potassium are applied, plants have a tendency to take up more than they need. Some soil specialists feel that "luxury consumption" is aggravated by shortages of other nutrients. Others feel that this problem is over-exaggerated. At any rate, limited resource farmers are unlikely to apply high enough rates of K to promote luxury consumption.

K Tie-up Problems are Usually Minor

Only about 1-2 percent of a soil's total K is in the available form, but even this is often enough to supply the needs of some crops. Tie-up of added K is usually not a problem. Some soils high in the 2:1 temperate clays such as montmorillonite can temporarily tie up some added K. (Clay types are covered in Chapter 2.)

Leaching Losses of K are Usually Minor

Available K is a cation (K^+) and is therefore somewhat resistant to leaching on most soils. However, leaching losses can be substantial on sandy soils (or others that have a low C.E.C.) where rainfall is high. In this case, it's best to "spoonfeed" K by making 2-3 applications if chemical fertilizer is used. Acidic soils lose more K by leaching than limed ones.

Recycling of K

Unlike N and P which accumulate mainly in the seed or grain, about 2/3rds of the K that plants take up remains in their leaves and stalks. Returning crop residues to the soil is a good way to recycle K.

The Potassium/Magnesium Balance: High applications of K can provoke magnesium deficiencies in some crops. For example, overuse of K in grass pastures has caused Mg deficiencies in both the grass and the livestock.

The secondary macronutrients: (Ca, Mg, S)

CALCIUM

- Calcium is not only an important plant nutrient but is also used as a liming material to lessen acidity.
- Even very acid soils usually have enough calcium to fulfill plant needs, although pH may be too low for good crop growth. Peanuts have unusually high Ca needs and often require gypsum applications.
- Available calcium has a plus charge and therefore has some resistance to leaching.

MAGNESIUM

- Magnesium deficiencies are most likely to occur in sandy, acid soils (usually below pH 5.5).
- Like calcium, Mg is a cation (Mg^{++}) is also fairly resistant to leaching, compared to nitrate N (NO_3^-).

The calcium/magnesium ratio: Mg deficiencies can be provoked if the ratio of Ca to Mg in the soil becomes too high, even though the soil contains enough Mg. This is more often a problem on sandy soils (or other low C.E.C. soils) where it's easy to upset the nutrient balance. When liming, it's a good idea to use dolomitic limestone (a mix of Ca and Mg).

Potassium-induced Mg deficiencies: Refer to the section on K above.

SULFUR

- Sulfur is used in protein synthesis and by the N-fixing rhizobia bacteria. It also forms part of several vitamins and is used in oil (fat) formation.
- Crucifer (Brassica) Family plants (cabbage, broccoli, turnip, etc.), onions, and asparagus have especially high S needs, followed by tobacco, cotton, and legumes.
- S deficiencies aren't common but are most likely to occur in highly leached soils (sandy, low C.E.C., high rainfall).
- Volcanic soils tend to be low in S; farmland near industrial areas usually receives more than enough S from the air.
- The high-analysis grades of chemical fertilizers are low in sulfur and may lead to deficiencies if used as the sole source of fertilizer continually.

Leaching Losses of Sulfur

The available form of sulfur is the sulfate ion (SO_4^-) which is readily leached, especially in sandy soils under high rainfall. A good part of the soil's sulfur is in the unavailable organic form which bacteria convert to available sulfur. Organic sulfur is an important reservoir of this nutrient, since it doesn't leach in this form. As with N and P, sulfur can become temporarily tied up when large amounts of low-nitrogen crop residues (i.e. those from non-legumes) are plowed under, because the decomposition bacteria need sulfur as well.

Sulfur retention: Appreciable amounts of available sulfur can be retained against leaching in subsoils high in tropical-type clays; plant roots can utilize this source.

The micronutrients

(Iron, Manganese, Copper, Zinc, Boron, Molybdenum)

- The micronutrients perform many vital functions, but are needed in very small amounts.
- The difference between toxic and deficient levels is often small. As little as 75 grams of Mo per hectare may cure a deficiency for several years, but 3-4 kg might severely injure plants. Boron is another touchy one.

Where to Suspect Micronutrient Deficiencies

Although less common than macronutrient deficiencies, micronutrient deficiencies can be just as serious when they occur and are favored by:

- Highly leached, acid, sandy soils.
- Organic soils (peats or those soils containing at least 20% humus by weight). Copper deficiencies are especially common on these soils.
- Soil pH's above 6.8-7.0, except in the case of Mo which doesn't become less available as pH is increased.
- Intensively cropped soils fertilized with macronutrients only.

Susceptible Crops: Vegetables, legumes, and tree crops are more prone to micronutrient deficiencies than cereal grains and pasture grasses. However, sorghum is very sensitive to iron deficiencies as maize is to zinc deficiencies. Table 10-5 in Chapter 10 lists the susceptibility of specific vegetables to micronutrient deficiencies.

Micronutrient Toxicities

Iron and manganese can become toxic to plants in very acid soils below pH 5.0-5.5 when they become too soluble. Poor drainage also promotes this problem. Boron and molybdenum can become toxic if over-applied.

How to Correct Deficiencies or Toxicities

- Adjusting pH: Molybdenum deficiencies can often be more effectively corrected by raising soil pH if very, acid. Raising pH is effective in alleviating iron and manganese toxicities (aluminum too), and improving drainage will also help.
- Soil applications of micronutrients: Effectiveness varies. Iron and manganese are very readily tied up when applied to soils where they're deficient. Special chelated forms are available which are less subject to soil tie-up. (See Chapter 9).
- Foliar applications: Since such small amounts are needed, it's practical to spray plant foliage with a very diluted micronutrient solution. This also avoids soil tie-up problems. Several applications may be needed. In some cases, foliar fungicides like Maneb (containing manganese), Zineb (containing zinc), and Cupravit (containing copper) are used to supply deficient micronutrients to vegetable and tree crops in conjunction with control of foliar fungal diseases. Application rates for micronutrients: See Chapter 9.

Chapter 7: Evaluating a soil's fertility

Deciding how much and what kind of fertilizer a farmer needs for her crops is a two-stage process:

1. The soil's present fertility level should be evaluated, ideally by soil testing.
2. Once the soil's present state of fertility is known, the most appropriate kinds and amounts of fertilizers can be determined, considering the following factors:

- Type of crop
- Feasible yield goal as determined by:
 - Yield-limiting factors such as available moisture, soil characteristics, weather, pests, and diseases.
 - Farmer management level
 - Available capital for needed inputs

- Expected cost/return based on likely yield and market value (more difficult to predict with vegetable crops than field crops).

In this chapter, we'll focus on stage 1 and cover the following methods of evaluating a soil's fertility:

- Soil testing
- Plant tissue testing
- Fertilizer trials
- Spotting visual "hunger signs"

Soil testing

Soil testing by a reliable lab is the most accurate and convenient method for evaluating a soil's fertility. Most labs will also make a fertilizer recommendation, too. This service is often free or very low-cost, yet is often underutilized by farmers and development workers.

Some Factors Affecting the Usefulness of Soil Testing

- Improper sampling procedures by farmers and extension workers are common and produce inaccurate results.
- The test for available soil nitrogen (in the form of nitrate N) isn't very accurate. That's because a soil's available N fluctuates, because it depends a lot on the kind and amount of crop residues present and the rate that bacteria will break them down to release nitrate N (this rate varies a lot with temperature and moisture). If the sample sits at the lab for a week or two, a falsely high nitrate reading is likely.
- Most labs don't routinely test for sulfur or micronutrients. Some of these tests aren't very accurate, anyway.
- The reliability of soil labs varies, not only in terms their accuracy in evaluating a soil's fertility, but also as far as the resulting fertilizer recommendations. More on this below:

Soil Lab's Aren't Necessarily Reliable

When different soil test labs analyze the same soil sample, there can be some large discrepancies in both the fertility evaluations and the fertilizer recommendations. In fact, recent studies of public and private (commercial) labs in the U.S. have brought to light some surprising differences. For example, in one of the studies conducted by the Rodale Research Institute (Emmaus, Pennsylvania), 4 soil labs were sent an identical sample and asked to make a fertilizer recommendation for lettuce. Their recommendations varied as follows: N: 65, 130, 130, 220 kg/ha; P₂O₅ 0, 0, 90, 220 kg/ha; K₂O: 0, 0, 35, 220 kg/ha. The resulting fertilizer cost ranged from \$75-\$235/ha. In another study, 5 labs were asked to analyze 4 sets of identical soil samples for 4 fields. The total cost of the fertilizer recommended by them ranged from a low of \$168 to a high of \$320.

How to Find a Reliable Lab

Despite these variations, soil testing is still a very useful tool if you can locate a reliable soil testing lab. The Ministry of Agriculture, agricultural schools, ag research stations, or fertilizer companies may maintain labs in your country. You can inquire among technicians and farmers as to their opinion of the labs and do some additional investigation as well. Here are some useful indicators of reliability.

- Adequate equipment and well trained technicians.
- Enough greenhouse/field trials with the area's soils to correlate soil test results with actual crop response to different rates of fertilizer. Soils vary in their response, so such correlation data is vital.
- Lack of bias: Labs run by fertilizer companies may be more interested in selling fertilizer than in accuracy, though not always. In some cases, labs don't consider the special circumstances of limited-resource farmers but gear their rates toward large farmers; this factor, in itself, can produce wide variations in fertilizer recommendations among labs testing the same soil sample.

NOTE: Even if the lab is biased, soil testing can at least provide you with valuable baseline data for "customizing" the recommendation to suit a farmer's actual circumstances.

- The lab should give credit for the farmer. A intended use of manure, compost, or green manure crops since this can substantially lower fertilizer needs.
- Farmer input: Good labs supply a detailed questionnaire for the farmer to fill out concerning farm size, past and future crops, past yields, yield expectations, past fertilizer applications, intended use of manure or green manure crops, limiting soil factors, etc.
- Sampling instructions: Reliable labs are likely to provide detailed written instructions on how to take and collect soil samples.

How to Evaluate a Lab's Fertilizer Recommendations

- Compare them with Table 9-4 in Chapter 9.
- Send an identical sample to two or more labs.
- Compare the lab's recommendation with trial strips using higher and lower rates.
- Plant tissue testing can be a useful supplement to soil testing since it can monitor N-P-K levels in the plant itself. (The section following soil sampling discusses tissue testing.)

What about Portable Soil Test Kits?

You can buy portable soil test kits for measuring NPK levels, but they definitely aren't accurate enough for several reasons:

- They're unlikely to be correlated with local soil conditions.
- Their reagents break down with time and may be difficult to replace.
- The color bar plates used to measure readings are often of poor quality and standardization in the cheaper kits.

Portable soil pH test kits are also available, and the better quality ones are accurate to within 0.1

0.3 pH units. They can be useful for troubleshooting, but a lab test will still usually be needed to determine how much lime is needed to raise the pH of an overly acidic soil. (Liming is covered in Chapter 11.)

What Useful Information Does a Soil Lab Provide?

- Most labs routinely test for:

Soil pH

C.E.C. (negative charge)

Available N, P, K, Ca, Mg

- Most labs don't routinely test for micronutrients or sulfur.
- The lab will give a fertilizer recommendation for NPK either in terms of kg/ha of N, P, and K or in terms of the actual kinds and amounts of fertilizers needed. The recommendation is based on the amount of nutrients already present in the soil and should also take into account the farmer's yield expectations.
- Liming: If the soil tests out overly acidic, the lab will give a liming recommendation.
- In dry regions where salt buildup is a problem, the lab will test both the soil and the irrigation water for salt content and make recommendations; there is usually an extra charge for this. (Chapter 12 covers salt problems.)

How Often is Soil Sampling Needed?

Where low to moderate rates of fertilizer are being used, once every 3-5 years is sufficient. That's because such rates feed the crop itself rather than also building up the soil's residual fertility.

What About Soil Testing and Organic Fertilizers??

Unlike chemical fertilizers which have an analysis label, the exact nutrient content of organic fertilizers, like manure and compost, is highly variable and difficult to judge. If this is so, is it worthwhile to test the soil in cases where organic fertilizers are used? Soil testing may still be a good idea for several reasons:

- If the soil is severely deficient in a nutrient like P or a micronutrient, some chemical fertilizer may have to be used to supplement the organics.
- Knowing the fertility status of the soil will allow you to determine which organic materials can best provide what is needed.
- The lab's pH test may indicate liming is needed. The lab can best determine how much lime is needed.

HOW TO COLLECT AND PREPARE SOIL SAMPLES

When to Sample

- At least 2 months before the results are needed. If farmers wait until a few weeks before planting, the lab is likely to become overloaded and unable to provide the results in time.
- Sampling may be easier to do in the wet season when the soil isn't as hard. In the case of flooded rice soils, check with the lab for the best sampling time. (While flooded, soils have different chemical properties than when unflooded.)

Avoid Improper Sampling

Improper sampling is a very common cause of inaccurate lab results. Each 200-500 gram sample sent to the lab may represent up to 15,000 metric tons of soil. One sign of a good lab is that it will provide sampling containers along with detailed instructions of how to take samples.

Involving Farmers in the Sampling Process

Avoid taking the samples on your own; instead, be sure to involve the farmer in the process. After all, extension should aim to “enable” farmers rather than create dependency. Also, the farmer's input is essential when it comes to mapping the farm and filling out information on past management, yield history, cropping plans, and expected yields.

The Sampling Procedure

The steps below provide general guidelines for sampling. Always consult the lab's instructions, too.

STEP 1: DRAW A MAP OF THE FARM, DIVIDE IT INTO SAMPLING UNITS, AND NUMBER THEM.

What is a sampling unit?: An area of soil that is likely to be uniform in its fertility. Even small farms usually have several sampling units.

How to Distinguish Sampling Units

Each of the following factors indicate likely differences in soil fertility:

- Soil color
- Soil texture
- Topography (slope vs. flat vs. depression)
- Past management (Use of manure, fertilizer, lime; type of crops grown. For example, new ground that has been in pasture for years will have a different fertility status than land that's been cropped steadily.)

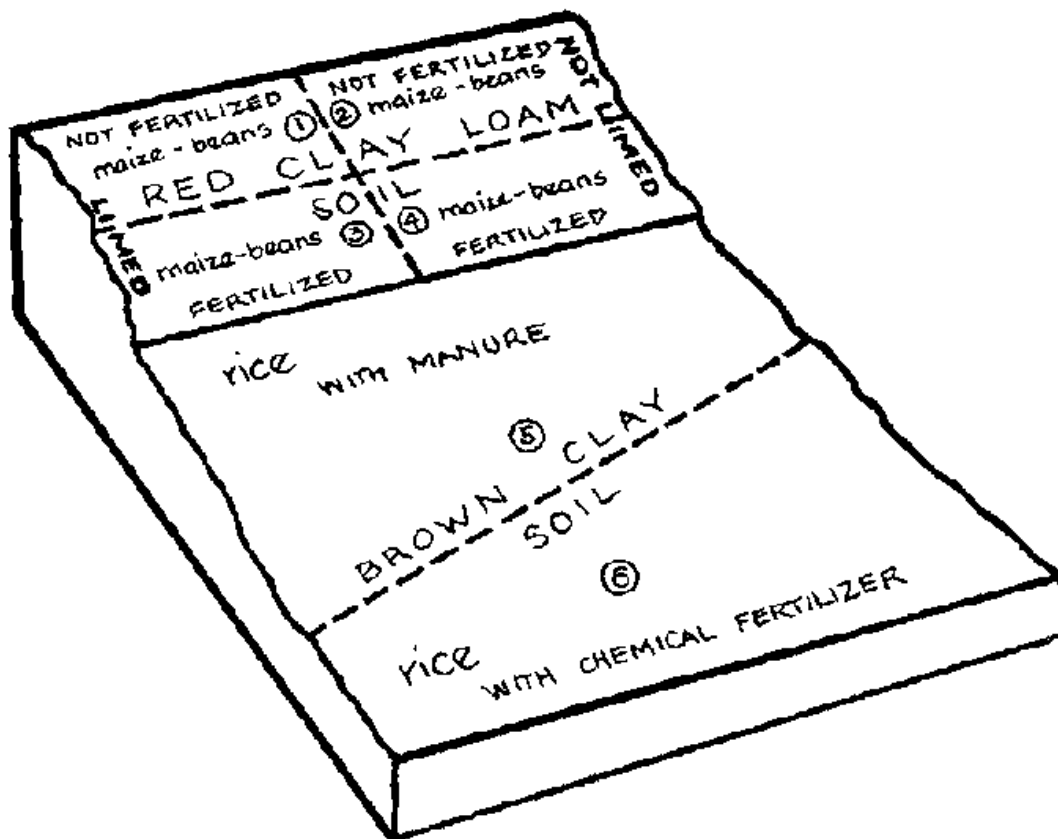
Mapping the Farm

The map isn't needed by the lab, but is used to delineate the different sampling units and serve as a record of which sample came from where. It's also a useful management tool for the farmer. If the farmer is agreeable, make an extra copy for yourself - it will be useful in further extension work with him. Here's how to map a farm:

- Start by drawing in the boundaries and the location of buildings, wells, and the fields along with their dimensions .
- Indicate variations in topography, slope, soil color, soil texture, and past use of fertilizers and lime.

- Indicate past, present, and future crops and their locations.
- Once the sampling units have been determined, draw their boundaries and number them.

FIGURE 7-1: Farm map denoting different sampling units.



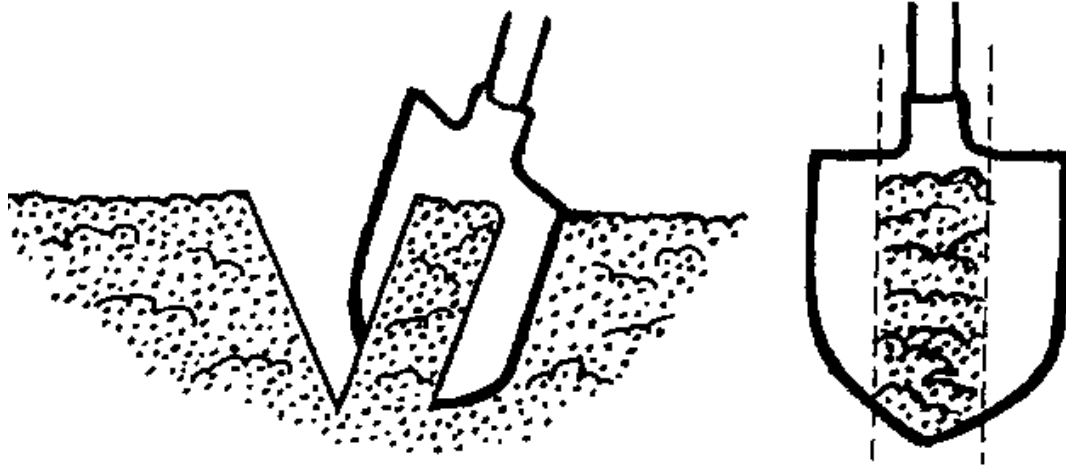
STEP 2: FROM EACH SAMPLING UNIT, COLLECT 10-20 SUBSAMPLES FOR COMBINING INTO A COMPOSITE SAMPLE REPRESENTING THAT UNIT.

It's important to realize that each sample sent to the lab is really a composite sample composed of 10-20 subsamples taken at random within that sampling unit.

Guidelines for Extracting Subsamples

- Tools: A shovel, machete or knife (for paring down the samples), and a pail or sturdy sack (for placing and mixing subsamples). Special soil sampling tubes or augers may be available on loan from the ag extension office but aren't essential.
- Depth to sample: Most labs want a uniform slice of the top 15-20 cm of soil, the normal depth of topsoil. Some labs may also request separate subsoil samples. If the field is severely eroded, the normal sample will also include some of the subsoil, but that's OK.
- Extraction method: If using a shovel, you can use several methods. The important thing is to end up with a uniform slice of soil from the surface to a depth of 15-20 cm. One way is to make a hole with about 45 degree sides to the right depth. Then use the shovel to trim off a 3-4 cm thick slice 15-20 cm deep. If a second person holds the face of the slice with one hand, it won't crumble apart. Scrape off any surface debris like stones or stalks before sampling.
- Use a random pattern: A zig-zag pattern is fine, but don't sample along fence lines, in fertilizer bands, under animal droppings, or in transition zones between sampling units.
- Uniform size: Each subsample should be of equal size. Use a knife or machete to pare down each one to a similar width and depth (see Fig. 7-2).
- If a zinc test will be done, don't collect subsamples in a galvanized pail.

FIGURE 7-2: (Left) Extracting a subsample using a shovel. (Right) Subsample after trimming with a machete.



STEP 3: MIX THE SUBSAMPLES TOGETHER THOROUGHLY, AND THEN TAKE OUT THE AMOUNT NEEDED BY THE LAB, AND PLACE IT IN AN APPROPRIATE BOX OR BAG.

- NEVER mix together subsamples from different sampling units!
- Drying: The soil can be slightly moist. If overly wet, it can be sun dried. Do not oven dry, as the heat will alter the soil's potassium, resulting in an erroneously high reading.
- Be sure to number each composite sample so it corresponds with the sampling unit from which it came.

STEP 4: HELP THE FARMER FILL OUT THE LAB'S INFORMATION SHEET.

Another sign of a good soils lab is its provision of a detailed information sheet requesting data on the farmer's situation. One purpose of the form is to provide extra information on the soil that's not revealed by the samples themselves (i.e. depth). In addition, it should attempt to evaluate the farmer's management level and the likely limiting factors affecting the intended crop's yield potential. The data requested should include most of the following:

- Farm size
- Soil depth
- Soil slope
- Soil drainage
- Past applications of fertilizer and lime
- Past crops
- Past yields
- Crop to be grown
- Variety to be used
- Intended use of compost, manure, or green manure crops
- Yield goal
- Capital available for fertilizer
- Limiting factors like insects, diseases, nematodes

A lab that requests little information isn't as likely to tailor its fertilizer recommendations to varying farmer circumstances.

Getting the Information: Depending on the culture and the farmer, there may well be hesitancy in providing some of the above data, especially regarding past yields and available capital. A lot may depend on the familiarity, trust, and credibility you have established with the farmer. It's important to explain the purpose the information will serve and yet not be overly insistent about obtaining it.

STEP 5: SEND THE COMPOSITE SAMPLES TO THE LAB.

Depending on your situation, the samples can be mailed in, taken to the local extension office, or delivered personally to the lab. Visiting the lab is a worthwhile experience; it will give a better idea of what goes on there, and the personnel can often provide very useful information on soils and fertilizer use.

STEP 6: MAKE SURE THE RESULTS ARE CONVEYED IN AN UNDERSTANDABLE FORM TO THE FARMER.

The form in which soil test results and fertilizer recommendations are given varies a lot with the lab and with the role played by the extension service. Often, there will be two parts to the results, the first being the fertility analysis of soil, and the second being the actual fertilizer recommendation. Even if a farmer or family member can read, the recommendation sheet may be too complex. In some cases, the lab mails the results to the local extension office where they are then put into a more readily understandable form.

Plant tissue testing

A growing crop can have its stem and leaf tissue tested for N-P-K levels in the sap. This can be done either in the field with portable kits or at a lab. (Labs can also measure micronutrient levels.) The uses and limitations of tissue testing are:

- Tissue tests are best used as a supplement to soil tests and can be tricky for nonprofessionals to interpret.
- Sometimes nutrient levels in plant sap aren't well correlated to those in the soil. Weather extremes, soil compaction, poor drainage, insects, and diseases affect nutrient uptake. Deficiencies of N, for example, can stunt plant size and cause P and K to "pile up" in the sap, resulting in falsely high readings.
- The tests are usually calibrated for higher yield levels than most small farmers should be aiming for. Low to moderate fertilizer rates, rather than high ones, give the best return per dollar (see Chapter 9), yet a tissue test may indicate a deficiency at these levels.

- One advantage of tissue tests is that they can spot deficiencies in a growing crop while there's still time enough to correct them. Portable tissue test kits cost from \$25-\$75, but some of the reagents need yearly replacement. Tissue testing is probably best left to trained agronomists.

Fertilizer trials

Well-run fertilizer trials can be very helpful. There are 3 kinds:

- Test strips
- Field experiments (farm experiments)
- Field tests (field trials, result tests)

Test Strips

Running test strips through a field is a quick and easy way to test crop response to different fertilizer rates and nutrient combinations. Test strips have less statistical significance than formal trials, but they do allow farmers to conduct some research on their own farms, which can be very useful. A researcher's test of statistical significance is usually a 95 or 99 percent likelihood that the results were due to the treatment applied rather than to chance. Farmers (and most of us) would probably settle for a much less stringent figure and try a new practice, even if there were only a 75 percent chance of getting a response.

To reduce the influence of soil variations, each treatment tested should consist of several strips 23 rows wide placed in different parts of the field. The soil should still be uniform visually and in terms of past management. Don't rely on just one season's results, since weather and pests can influence yields.

Fertilizer rates for test strips: Consult your extension office and Chapter 9 of this manual.

Field Experiments (Farm Experiments)

These are designed to be statistically valid and require much more effort and care to set up and manage. They are designed to determine the most profitable kind and amount of fertilizer needed for a given crop and soil. Suppose you want to try 3 different rates of fertilizer. It's not simply enough to mark out one test plot and 3 fertilized plots. Each of these 4 "treatments" needs to be replicated 3-4 times and laid out within a bloc in a randomized manner. Each of the 12-16 plots are only a few rows wide and several meters long. Plot size, plant population, and fertilizer rates have to be carefully measured, along with yield differences. It's a good idea to repeat a trial for 2-3 years to take into account weather variations.

Formal experiments require much time, skill, attention to detail, and scientific discipline. They are not something that you should do on your own. However, you can play a very useful role in a well conducted and ongoing fertilizer testing and demonstration program.

Field Tests (Field Trials, Result Tests)

This type of research tests the best fertilizer type and rate determined from the farm experiments above, but this time under actual farming conditions. There are normally just 2 plots: the "control" plot (traditional practice) and the "treatment" plot (improved practices). Rather than rely on randomization and replication of the plots on each farm, the field test gets its statistical validity from being conducted on a number of farms with fairly similar conditions. In most cases, fertilizer will be only one of several improved practices making up the treatment plot. The plots should be large enough so that realistic farming methods can be used. To be valid, the farmer and other usual labor should carry out the practices themselves with some initial instruction and supervision by the extension worker.

Experiments/Trials vs. Demonstrations

The experiments and trials above seek to develop fertilizer recommendations for local conditions that will be the most affordable and profitable for the farmers involved. Don't succumb to the natural and prevalent temptation to use such tests as demonstrations. After all, a demo is designed to provide farmers with "living proof" of the benefits of a new practice (or package of practices) - one that has first proven its worth under local conditions. This syndrome of promoting without adequate prior testing has cost many an extension worker an irreparable loss of credibility. Testing is always the first stage; promoting comes later.

NOTE: For more information on experiments, trials, and demos, refer to the Peace Corps/ICE manual, Traditional Field Crops (M-13).

Using visual "hunger signs"

Severe nutrient deficiencies often produce telltale changes in plant appearance, particularly in color. Spotting these "hunger signs" can be useful in diagnosing fertilizer needs, but be aware of several drawbacks:

- Some hunger signs are readily confused with each other or with other problems such as insects, diseases, and nematodes. Even trained field technicians may be unable to make a definite diagnosis without lab tests.
- If more than one nutrient is deficient, the hunger signs may be too ambiguous for accurate diagnosis.
- "Hidden hunger": Hunger signs don't usually appear unless a nutrient deficiency is serious enough to cut yields by 30-60 percent or more.
- It may be too late to correct deficiencies by the time hunger signs appear.

Hunger sign diagnosis is likely to be most useful in areas where only one or two nutrients are commonly deficient on a crop that will manifest unusually clear symptoms. For example, maize shows the most clearly recognizable symptoms of zinc hunger of any crop. Nitrogen deficiency is relatively easy to spot, although a number of other factors can cause similar symptoms.

How to Spot Hunger Signs: Hunger signs for common crops are described in Appendix E. Refer also to Appendix H for useful references with color plates.

Chapter 8: Using organic fertilizers and soil conditioners

What are organic fertilizers?

The term "organic" can mean several things, but in the case of fertilizers it refers to sources of plant nutrients that are naturally occurring such as:

- End products of plants and animals such as compost, manure, bone meal, and green manure crops. (These will be covered shortly.)
- Minerals like rock phosphate that are mined from the earth and used without undergoing any chemical treatment.

Unlike the organics, chemical fertilizers are derived from a chemical manufacturing or synthesizing process. Some examples are urea (made by combining carbon dioxide and ammonia), single superphosphate (made from rock phosphate and sulfuric acid). The distinction between chemical and organic fertilizers can be confusing, because the term "organic" technically refers to any compound containing carbon. Urea contains carbon, yet is considered a chemical

fertilizer; likewise, rock phosphate has no carbon, yet is considered an organic fertilizer. That's because the most popular meaning of "organic" is "naturally occurring".

Organic vs. chemical fertilizers: which are best?

There's no one right answer to this question. Both organic and chemical fertilizers have their appropriate uses in small farmer agriculture in the Third World. Both have their pros and cons. They can also be used together. What's best for a given situation depends on many factors such as the farmer's circumstances, type of crop, area involved, and the availability and costs of organic and chemical fertilizers. First, let's go over the pros and cons of each type:

Possible Advantages of Organic Fertilizers

- Organics like compost and manure are generally free or very low cost for most farmers.
- Organic fertilizers take relatively little skill to use properly.
- Plant- or animal-derived organics like compost or manure usually contain significant amounts of micronutrients in addition to macronutrients such as N, P, and K.
- Plant- or animal-derived organics like manure not only supply plant nutrients but also organic matter which improves soil physical condition, stimulates beneficial soil microorganisms, and provides all the other benefits covered in Chapter 2.
- Much of the nitrogen and phosphorus in organics is in a slow-release, organic form. This is a plus for nitrogen which is susceptible to leaching losses when supplied by chemical fertilizers. (However, as opposed to well-rotted manure, fresh manure has much of its N in the quick-release inorganic (mineral) form.
- The phosphorus in organic fertilizers is less prone to soil tie-up than that from chemical fertilizers, making it more available to plants.

Possible Disadvantages of Organic Fertilizers

- Most plant derived organics like compost and manures are low-strength fertilizers; this means very large amounts (i.e. 3-8 kg/sq. meter or 30,000-80,000 kg/ha per crop) must be applied to supply enough nutrients for crop growth and to add enough humus to benefit soil physical condition. Most small farmers aren't likely to have enough organic fertilizer to cover all their crop land adequately.

NOTE: Some animal-derived organics like blood and fish meal approach the nutrient content of some chemical fertilizers but are usually too expensive to be cost-effective or aren't available locally.

- The exact nutrient content of most organics like compost or manure varies a lot.
- It takes a good deal of labor to apply most organics or to make compost because of the large amounts needed.

Possible Advantages of Chemical Fertilizers

- They are high-analysis nutrient sources. For example, 50 kg of 10-5-10 chemical fertilizer has about the same NPK content as 1000 kg of typical manure. This means much less labor is needed to apply an equal amount of nutrients.
- Unlike most organics, the nutrient content of chemical fertilizers can be verified from the label. If the farmer has her soil tested, she can usually buy the chemical fertilizers that will supply what's needed.

Possible Disadvantages of Chemical Fertilizers

- Although chemical fertilizers are very cost-effective when applied correctly in conjunction with overall good management, they do cost money. As a rough figure, a farmer relying totally on chemical fertilizers would have to spend about \$75-\$125 (U.S.) per hectare per crop (based on unsubsidized prices). Trying to rely entirely on chemical fertilizers isn't feasible for most limited-resource farmers, many of whom have no access to reasonable ag credit.
- Most Third World countries must import chemical fertilizers which can be a drain on their balance of payments. Even if they manufacture their own, the fertilizer plants are heavily dependent on foreign inputs.
- Compared to organics, the proper application of chemical fertilizers takes considerably more skill as far as dosage calculations, timing, placement, and application methods. Many farmers are not using them efficiently.

Some Other Issues

- **Effect on Nutritional Value:** Most researchers agree that when vegetables are grown on low-fertility soils and are underfertilized, their vitamin contents are abnormally low, especially in the case of vitamin C and carotene (the latter is converted to vitamin A in the body). Most research bodies, including the National Cancer Institute, now believe that vitamin C and carotene help prevent several types of cancer. (Pre-formed vitamin A [retinol] is found only in animal products like liver but hasn't been shown to be as effective an anti-carcinogen as the carotene found in dark green, orange, or yellow vegetables and fruits.) Both chemical and organic fertilizers can increase overall vitamin content (especially that of vitamin C and carotene) when applied to vegetables (especially leafy greens like pak choy and amaranth) grown on low-fertility soils.

Until recently, most studies showed no nutritional differences between organically and chemically fertilized crops. Now, new research (including more accurate analysis techniques) has shown that overly high (as opposed to normal rates) of chemical N fertilizer may markedly lower the vitamin C content of leafy vegetables like lettuce and Chinese cabbage. Heavy applications of compost and well-rotted manure don't have this effect, because they release N slowly; however, excessive rates of fresh manure are likely to have an effect similar to chemical N fertilizers. (This research is summarized in the American Soc. of Agronomy Special Publication 46: Organic Farming.)

Researchers have known for many years that excessive rates of chemical N fertilizer or fresh manure may produce excessive nitrate levels in leaf vegetables like spinach. In plants, nitrates are converted to nitrites which are toxic in themselves, but can also be further changed into nitrosamines which are strongly linked to stomach cancer. Compost and well-rotted manure release their N slowly enough to avoid this problem.

- **Do Chemical Fertilizers "Poison" the Soil?** Organic advocates often claim that chemical fertilizers destroy beneficial soil life as well as good tilth (workability), eventually ruining productivity. However long-term studies haven't confirmed this. The fact is that soil decline (aside from erosion) is directly linked to a drop in soil humus, which occurs when soils are continually cropped without making large and regular applications of organic matter. Chemical fertilizers themselves don't speed up the loss of humus, but may actually slow it down, since higher yields produce more crop residues that can be returned to the soil. On the other hand, using organics in sufficient amounts can automatically assure that humus level is maintained and possibly increased.

Overuse of chemical nitrogen fertilizer has been linked to nitrate contamination of rivers, lakes, and wells due to leaching and runoff of the excess N. However, fresh manure can also release

large amounts of nitrates and may cause similar problems when large quantities are applied or stockpiled.

Likewise, phosphorus runoff from farmland may promote excessive algal growth in lakes and reservoirs leading to oxygen depletion and fish kill. However, both chemical fertilizers and animal manure will produce surface runoff of P, especially when applied to sloping fields without being worked in thoroughly.

- **The Energy Cost of Chemical Fertilizers:** Nearly all the nitrogen in chemical fertilizers is derived from ammonia gas which is formed by combining hydrogen (made by burning natural gas) with nitrogen gas taken from the atmosphere. When critics of chemical fertilizers say that they are too petroleum dependent for their manufacture, they're referring to this process. Surprisingly though, only about 3 percent of the natural gas in the U.S. is used in making N fertilizer. One study showed that if the amount of natural gas needed to heat an average Midwest home were converted into N fertilizer, it would produce enough extra maize to feed 275 people for a year!

However, as we'll see, there's much that can be done about the faulty application practices and poor management that waste a good deal of the chemical fertilizer used worldwide.

HELPING FARMERS DECIDE WHETHER TO USE ORGANIC OR CHEMICAL FERTILIZERS

Now that we've covered the pros and cons of organic and chemical fertilizers, here are the main factors that should govern a farmer's choice:

- Given their low cost, simplicity of use, and multiple soil benefits, the use of organics should be strongly encouraged, especially for limited resource farmers. However, chemical fertilizers may be the only present feasible alternative where organics are in short supply, are of poor nutrient value (i.e. poorly stored manure), or where labor is inadequate to handle and apply them. Given the current state of suitable organic technologies, there are many Third World areas where it's still not possible to become totally reliant on organic fertilizers for all crops.
- **Size of field and type of crop:** As with chemical fertilizers, organics are beneficial to all crops when applied properly. However, since many small farmers aren't likely to have enough organic fertilizer to cover all their land, they're usually better off using what's available on their smaller plots which are usually used for vegetables. This will enable them to apply a high enough rate to supply a beneficial amount of nutrients and organic matter. If enough is available, it can also be applied to the larger fields which are typically devoted to staple cereals and pulses (grain legumes) such as maize, sorghum, and cowpeas.

NOTE: One type of organic fertilizer that is often feasible for larger fields is green manure which is covered later on in this chapter.

- Where organics are in short supply, field crops will often benefit from chemical fertilizers, though cost may be prohibitive where credit isn't available. Where organics are available or are of poor nutrient value, a good case can be made for using chemical fertilizers on small plots, too, such as vegetables, at least as a temporary measure. On small areas, the cost of chemical fertilizer, which is roughly about 1 U.S. cent per sq. meter (mid-1980's prices), becomes more reasonable.

- Organic and chemical fertilizers often work very well together. For example, chemical fertilizers can be used to supplement animal manure if it is low in nutrient value or if supplies are limited. Chemical fertilizers can also be used to supply specific nutrients when available organics are unable to do so. A good example would be the use of ammonium sulfate fertilizer as a nitrogen sidedressing on vegetables in cases where the only available organic fertilizer is poorly-stored manure that is low in N. Low-P soils may require the addition of a chemical fertilizer, such as superphosphate, in conjunction with organic fertilizers. Likewise, low-nutrient organic soil conditioners, such as rice hulls and sawdust, can be used along with chemical

fertilizers to improve both the physical condition and the fertility of clayey soils. In addition, organic fertilizers help reduce the tie-up of chemical fertilizer phosphorus.

In summary, both organic and chemical fertilizers have their appropriate uses. Many farmers may find that both have a place on their farms, but they will usually be best off trying to maximize the use of organics.

Some examples of successful farming using organic fertilizers

Slash-and-burn agriculture

Also known as shifting cultivation, this traditional cropping system was once widely practiced throughout the humid tropics. Because of increasing population pressure on the land, it's now confined mainly to the dense forest areas of the Amazon Basin and S.E. Asia. Here's a brief description:

- Land is incompletely cleared by hand-cutting and burning trees and vegetation. Although burning destroys some nutrients like N and S, most of the others remain in the ash as fertilizer. The organic matter in the burned vegetation is lost, but HS we'll see, this isn't serious.
- Crops are grown on the land for 2-3 years, usually in a mixture of short-cycle staples like grains, pulses, and vegetables along with longer-term ones like yams and cassava. The plants utilize the naturally-accumulated nutrients built up from the fallow period (see below). Yields are fair the first year, but then rapidly decline, forcing the land to be temporarily abandoned after several years of cropping.
- The land then reverts to a natural vegetation fallow for 5-10 years which rejuvenates the soil in several ways. Deep-rooted tree species recycle leachable nutrients like N and S which are returned to the soil surface in the leaf fall. Some of the fallow vegetation may be leguminous and actually add N to the soil. The fallow period also increases the amount of soil humus and helps prevent a buildup of insects and diseases.

Slash-and-burn farming requires no outside inputs and is in complete harmony with the environment, as long as an adequate fallow period can be maintained. Unfortunately, in many areas, population pressures have resulted in shorter fallows and increased burning which kills off trees and brush, leading to deforestation, erosion, and soil depletion.

Mixed gardening

This is another traditional system that is self-sustaining in fertility. Like slash-and-burn, it's best adapted to the humid tropics where rainfall is adequate for year-around crop production. Unlike slash-and-burn, it's a permanent system with no fallow period and is practiced on smaller plots (typically 300-500 sq. meters), since it involves no staple grain production (although root crops like yams and cassava are usually grown). The major features of mixed gardening are:

- It is an integrated mixture of up to 30 or more annual and perennial crops plus several types of livestock like pigs and poultry; it may even include a fish pond. It provides the family with vegetables, fruits, spices, cooking oil, eggs, meat, fiber, medicines, weaving and building materials (i.e. bamboo, coconut palms), and firewood, etc.
- The crops are selected and interplanted to complement each other and achieve maximum land use efficiency. A mixed garden resembles a tropical forest with a multi-storied canopy. At ground level, there will be low-growing or trailing plants like sweet potatoes, taro, squash, herbs, and vegetables. At the next level may be coffee, cassava, banana, and papaya. Taller trees like avocado, citrus, and breadfruit will form the next canopy, followed by another of higher coconuts. Some of the trees and even the home's walls and thatched roof may be used to support climbing vines like yams and yardlong beans. This multi-storied arrangement provides maximum plant density and utilization of space.

- The system is self-sustaining in fertility because of nutrient recycling from manure and compost production, kitchen wastes, leaf fall, and N fixation from legumes. It's also virtually immune to soil erosion because of the ground cover.
- Until recently, the value of mixed gardening was often ignored by development “experts” or even derided as being outdated or unproductive (from a cash-cropping viewpoint). Fortunately, its value has now been “rediscovered”. It's important to note that it, in some cases, it may be possible and advisable to combine elements of Western gardening and mixed gardening. The Peace Corps/ICE office has several useful pamphlets on mixed gardening (see the bibliography in Appendix H).

Agroforestry

This is a land use system that combines trees with crop plants and/or livestock to increase overall production and income and to improve ecological stability. Some agroforestry systems are centuries old, but, like mixed gardening, this is a fairly new field of research. In fact, mixed gardening is a type of agroforestry. Although agroforestry doesn't always rely solely on organic fertilizers or self-sustaining fertility, most systems will decrease the dependence on chemical fertilizers. Agroforestry systems may have several benefits:

- Stabilization of hilly land.
- Maintenance and improvement of soil fertility: The deep taproots of trees can recycle nutrients lost by leaching. In addition, leguminous trees such as leucaena (*Leucaena leucocephala*) and *Sesbania* can fix considerable nitrogen.
- Improvement of the micro-climate through the effects of partial shading and the mulching effect of the leaf litter, which reduces the drying and hardening of the soil.

Here are two examples of agroforestry systems:

- Alley-cropping: In this system, leguminous trees like leucaena and madre-de-cacao (*Gliricidia*) are planted in rows 3-4 meters apart with food or forage (animal feed) crops grown in-between. The trees enrich the soil by fixing nitrogen from the air, and their leaves and pods provide a high-protein animal feed. The leaves, which are high in N, can be cut and carried to the non-legume crop for use as fertilizer or mulch; they can also be used for composting.
- Livestock/forage systems: Many leguminous trees like *Leucaena*, *Gliricidia*, *Calliandra*, and *Sesbania* have nutritious leaves palatable to livestock. (*Leucaena* leaves are toxic to non-ruminants.)

The regenerative agriculture movement

Also known as “biological” or “sustainable” agriculture, the origins of this movement go back a century or more. It has received new impetus (mainly in the U.S. and Europe) during the past 10 years, due to ever-increasing ag chemical prices and growing concern over pesticide usage, accelerated erosion, and other problems like nitrate pollution. The latter is partly attributable to the overuse of N fertilizers. The main principles and practices of regenerative agriculture are:

- It aims to sustain and support the environment instead of exploiting it.
- The use of insecticides, herbicides, and other biocides is minimized or eliminated. Control of weeds, insects and diseases is accomplished through natural, biological, or mechanical controls such as crop rotations, cultivation, resistant varieties, predator insects, and biological insecticides.

- Chemical fertilizers are minimized or eliminated. Soil fertility is maintained or improved by:
 - Crop rotations involving legume cover crops and green manures to add nitrogen.
 - The use of animal manure and “natural” fertilizers such as rock phosphate.
 - Stimulating a beneficial level of soil microorganisms that improve the availability of nutrients like nitrogen and phosphorus.
 - Soil erosion is controlled by the use of crop rotations and cover crops that provide erosion protection with their ground cover.
 - Livestock is usually included in regenerative farming systems to utilize forage rotation crops and provide manure. Hormones and the prophylactic use of antibiotics is eliminated.
- Although much more needs to be learned about regenerative ag before it can be widely and profitably adopted, some U.S. and European farmers have been making a successful transition toward this system, even on larger farms. Regenerative ag is not merely conventional farming without chemicals; nor is it simply a matter of reverting to the traditional practices of earlier years. Given the modern-day economic realities of farming and the advances in pertinent research areas such as soil microbiology and cover-cropping, new practices and techniques need to be developed and tested. Over the years, the USDA, U.S. ag universities, and agribusiness haven't shown much interest in regenerative ag. However, since the mid-1970's, there has been an increasing amount of long-awaited, valid organic farming research done by universities or by private organizations like the Rodale Research Institute in Emmaus, Pennsylvania.

As with most ag research, that concerning regenerative ag is very location-specific and has limited transferability from one area to another. This means that considerable adaptive research will be needed.

(For a summary of the current status of “organic” farming, see the American Soc. of Agronomy Special Pub. 46 listed in the bibliography in Appendix H.)

How to use organic fertilizers and soil conditioners

ORGANIC FERTILIZERS vs. STRAIGHT SOIL CONDITIONERS

“Organic fertilizers” is a broad term and actually includes 3 categories:

- Straight soil conditioners such as rice hulls and sawdust.
- Straight organic fertilizers such as fish meal and wood ashes.
- Combination organic fertilizers-soil improvers such as compost, manure, and green manure crops.

We'll cover all of these and also deal with mulching and earthworms.

Straight soil conditioners and their uses

Coarse materials like rice hulls (husks), peanut shells, and sawdust have very low nutrient value but are very useful for loosening up clayey soils. As mentioned in Chapter 4 on seedbed preparation, rice hulls are also very useful for making a good nursery seedbox soil mix for raising transplants. These materials can also be used as a surface mulch. Contrary to popular belief, sawdust doesn't make the soil more acid.

Beware of N tie-up: Since these materials are very low in nitrogen, adding large amounts to the soil can cause a temporary N tie-up while they're decomposing, unless extra N is added in the form of organic or chemical fertilizers. Roughly 1 kg of actual N should be added to the soil per

100 kg of low N material; this equals about 2 kg of urea fertilizer (45% N) or 200 kg of compost or manure. You can also avoid N tie-up by first composting these coarse materials with high-N materials like manure and young green grass. (Using rice trolls, etc. as a surface mulch is unlikely to cause N tie-up unless they're worked into the soil.)

Straight organic fertilizers and their uses

Some organics like blood meal, fish meal, and cottonseed meal have much higher nutrient contents than compost and manure. Because of this and the fact that some of them are expensive (they're in demand as livestock feed), they're applied at rates too low to improve soil physical condition.

TABLE 8-1

Nutrient Value of Some Straight Organic Fertilizers

	N	P ₂ O ₅	K ₂ O
Bat guano	10%	4%	2%
Blood meal	12%	2%	1%
Bone meal, steamed*	2%	26-30%	0%
Coffee grounds	2%	0.3%	0.3%
Cottonseed meal	6%	3%	1%
Feathers	15%	1%	1%
Fish meal	10%	4%	1%
Hair	12-16%	1%	1%
Rock phosphate*	0%	31-33%	0%
Seaweed (kelp)	0.2%	0.1%	0.6%
Wood ashes	0	1-2%	5-10%

* Much of the P in bone meal and raw rock phosphate is insoluble and only very slowly available.

Characteristics of Some Straight Organic Fertilizers

Bone Meal: Raw bone meal consists of cooked bones ground into a meal without removal of the gelatine or glue. Steamed bone meal has been steamed under pressure to remove some of the gelatine. Both types contain good levels of phosphorus and calcium, but much of the P is in a very slowly, available form which limits its immediate effectiveness. It works best when broadcast and worked into acid soils high in organic matter; it should be very finely ground to promote its reaction with the soil and the release of available P.

Rock Phosphate: It's considered an organic fertilizer, since it's mined from the earth and used either raw or after heat treatment, which improves its P availability. About 90% of the P in raw rock phosphate is insoluble and largely unavailable. As with bone meal, it works best on acid soils high in organic matter and should be broadcast in a finely-ground form. Heat-treated rock phosphate is discussed in Chapter 9 under phosphorus fertilizers. It is known the mycorrhizae fungi (see Chapter 1) help improve the P availability of rock phosphate.

Wood Ashes: Although an excellent source of K, they're also a very potent liming material. Even moderate applications have raised soil pH too high when done regularly. In fact, the Univ. of Connecticut experiment station now recommends applying no more than 100-150 grams (about 300-450 cc) per sq. meter per year. There's now evidence that trees in areas affected by industrial pollution (or vehicle exhaust) may accumulate heavy metals such as lead and cadmium which end up in the ash. Studies have shown that leafy or root crops such as lettuce and beets can absorb heavy metals from the soil. (Where soil lead levels are high, plant uptake can be effectively minimized by keeping the pH above 6.0 and the soil organic matter content above 25% - a very

high level.)

Sea Cucumbers (Holothurians): The PATS ag trade school on Ponape Island in Micronesia uses these marine animals as an effective fertilizer on vegetables. They are first fermented in a drum for 10-14 days and then applied as a 50-50 mix with water as a sidedressing to growing plants. Unfortunately, the fermentation produces objectionable odors; nonetheless, sea cucumbers are considered to be a promising fertilizer for the Pacific islands.

Seaweed is really too low strength an organic to rank in this group, but it's great as a mulch and soil improver. It's also an especially good nutrient source when applied at comparable rates to compost and manure, because it contains all known minerals. It should first be washed with fresh water or exposed to rainfall to avoid possible salt problems, although this causes some nutrient loss.

Diluted seawater is currently being studied as a possible source of micronutrients.

Combination organic fertilizers-soil conditioners: Manure, compost, and green manure crops

MANURE

If properly stored and applied, manure is a great nutrient source and soil conditioner. There's also some evidence that it may contain other growth-promoting substances like natural hormones and B vitamins.

Fertilizer Value of Manure

Table 8-2 compares the approximate NPK contents of various animal manures. As we'll see, however, the actual nutrient content of a manure is highly variable, since it's influenced by other factors aside from animal species.

TABLE 8-2

Approximate Composition of Various Animal Manures

KG OF NUTRIENT PER 1000 KG OF MANURE

Fresh manure with

Bedding or Litter

Moisture Content N* P2O5 * K2O*

Chicken 70% 11 11 5

Sheep, Goat 70% 10 7.5 10.5

Cow 86% 5.5 2 5

Horse 80% 6.5 2.5 6.5

Pig 87% 5.5 3 4.5

Rabbit 60% 15 10 10

* N = nitrogen; P2O5 = phosphoric acid; K2O = potassium oxide (potash)

Manure varies greatly in nutrient value: Although Table 8-2 shows that rabbit, sheep, and poultry manures are richer in nutrients than cow manure, that's not always the case. In fact, the nutrient content can vary greatly, even among animals of the same species. The reason is that the fertilizer value of a manure is also greatly affected by diet, amount of bedding, storage, and application method.

- Diet: The N content of fresh manure is directly related to the amount of protein in the animal's diet. For example, pigs fed a low-protein diet of mainly maize will produce manure lower in N than those fed a higher-protein ration.
- Amount of bedding: Animal urine contains about 30-50% of the total N and 50-80% of the total K. It will be largely wasted unless animals are penned and bedding is used to soak it up.

However, most bedding such as straw and sawdust is very low in nutrient value, and high amounts will greatly dilute the manure's fertilizer value. In fact, manure with excessive bedding may actually create a temporary N tie-up in the soil.

- Storage method: Outdoor storage without cover results in high nutrient losses (esp. N and K) due to leaching by rainfall or excessive drying out of the pile (the latter increases the loss of N as ammonia gas).
 - Application method: Ideally, manure should be worked into the soil immediately after application. Fresh manure can lose up to 25% of its N in a day and 50% in 2 days. The same applies to manure that is left exposed to the elements before collection.
- As a rough figure, 1000 kg of fresh manure with some bedding contains about 5 kg of N, 2.5 kg of P₂O₅, and 5 kg of K₂O. This works out to a 0.5-0.25-0.5 fertilizer formula (see Chapter 9 on chemical fertilizers). However, only about 50% of the N and 20% of the P in fresh manure is actually available to the crop during the first few months. The rest is in the more slowly-released organic form which must first be mineralized by soil microbes. Manure can also be a good source of micronutrients, especially from animals fed balanced rations.

"Hot" vs. "Cold" Manures: Fresh pig, poultry, and sheep manures are often referred to as "hot" manures, since they are likely to "burn" (injure) plants or prevent seeds from sprouting if applied too heavily or too close to planting time. In fact, most fresh manures can be considered "hot" with the possible exception of rabbit manure. Aged (well-rotted) manure that has partially decomposed can be considered "cold"; it releases nutrients more slowly and is likely to injure crops.

Amount of Manure Produced

TABLE 8-3.

Amount of Manure Produced Annually Per kg of Live Weight

Animal	Solids	Urine	Total Wet Wt.	Total Dry Matter
Horse	14.4 kg	3.6 kg	18 kg	4 kg
Chicken	8.4	0	8.4	4.3
Cow	19	8	27	3.8
Pig	18.2	12.2	30.4	4.0
Sheep	8.2	4.2	12.4	4.0

As Table 8-3 shows, farm animals produce large amounts of manure; the problem is collecting it. Encouraging farmers to pen free-ranging animals at night will help increase the supply. Notice that the total amount of actual dry matter produced is very similar among the animals.

Storage and Application Guidelines for Manure Fresh vs. Aged (Composted) Manure

Manure can be applied in either form. Fresh manure is more likely to injure plants or seeds, since it can release harmful ammonia fumes. Fresh poultry, sheep, and pig manure are the most likely to cause injury. On the other hand, fresh manure usually provides more readily-available nitrogen. (The one exception is anaerobically composted manure (see below), half of whose total N is in the readily-available ammonium form). Fresh manure can be safely used if applied a week or two in advance of planting and thoroughly worked into the topsoil to dilute it.

Aged (composted) manure will have shrunk to about 40-60% of its original volume. If protected from rain during rotting and storage, composted manure will be roughly twice as concentrated in nutrients, except for nitrogen, considerable amounts of which can be lost to the air as ammonia gas. Aged manure releases its N more slowly since much of it is changed into the slow-release organic form during composting. This is actually beneficial since it lessens leaching losses (organic N doesn't leach) and also provides N over a longer period.

How to Store Manure

If manure is not applied fresh, it can either be composted together with low-N residues like rice hulls and straw or be put in a pile by itself to rot. Manure piles should be protected from the elements. Rain will leach out soluble nutrients like potassium and nitrate N, while sunlight can cause excessive drying out of the pile which increases the loss of N as ammonia gas. According to how the pile is managed, it will undergo either an aerobic (with oxygen) or anaerobic composting (partial decomposition) process.

- Aerobic composting occurs in loose, semi-moist manure piles where oxygen is plentiful. Losses of N due to ammonia volatilization are roughly 30-50%; most of the remaining N is in the slow-release, organic form. If the manure's N content is adequate, the fungi and bacteria responsible for composting will complete the process within 3-8 weeks and will generate considerable heat from their metabolic activities. Additional water may be needed to maintain the pile in a semi-moist condition.
 - Anaerobic composting occurs in compact, wet manure piles where oxygen is excluded. It is a slower process, but N losses are much lower (as long as the pile is kept wet), and shrinkage of the pile is less. About half of the remaining N exists as readily-available ammonium, the remainder being in the slow-release, organic form. Unfortunately, such moist, anaerobic piles produce more odors and attract more flies than aerobic piles. Covering the pile with black plastic will minimize these problems and also help to maintain anaerobic conditions by reducing moisture loss and excluding air. Manure can also be used for methane production in anaerobic biogas digesters and the residue used as a fertilizer/soil conditioner.
 - Biogas production: Manure can be mixed with water and anaerobically fermented in a digester tank to form biogas (65% methane, 35% carbon dioxide), which can be used for cooking, heating, lighting, and even for running engines. The digested residue (called sludge) consists of 90% liquid and 10% floating solids and is a soil conditioner and low-strength fertilizer. However it must first be aged and aerated in a shallow pond for 2-4 weeks before application to dissipate plant-injurious substances like hydrogen sulfide.
- NOTE: Biogas production is more complex than popularly believed, which has led to many failures. For more information, refer to the Biogas/Biofertilizer Business Handbook, Peace Corps/ICE Reprint R-8, 1982.

How to Apply Manure

- A good way to apply manure is to spread it evenly over the bed and work it thoroughly into the topsoil before planting or transplanting.
- If double-digging is done (see Chapter 4), manure (or some other kind of organic fertilizer/conditioner) should also be worked into the subsoil.
- Fresh manure should ideally be applied 1-2 weeks in advance of planting or transplanting and thoroughly mixed with the topsoil to avoid the possibility of plant injury.
- When crops like squash and melons are planted in "hills" (clusters of seeds spaced a meter or so apart), manure should be thoroughly worked into the hill area itself.
- If manure is scarce, it can be applied in strips or slots centered over the row, instead of covering the entire area.
- Whatever method you use, be sure to work the manure into the soil immediately to avoid loss of nitrogen as ammonia gas (up to 50 percent in just 2 days). Well-rotted manure won't release ammonia, but may have lost a considerable amount during the rotting process. (However,

manure that has been anaerobically composted may be susceptible to some ammonia loss, because about half its N exists in the ammonium form.)

A warning about human, dog, cat, and pig manures: All are likely to contain parasites and disease organisms that can be transmitted to humans. Most composting methods can't be relied upon to kill these bad guys. Pregnant women should be careful not to handle cat manure which can spread a disease called toxoplasmosis that can harm the fetus. Pig manure is OK to use on most crops except those like carrots and lettuce whose edible parts are in contact with the soil.

Don't use feedlot manure: Cattle fattened in feedlots are fed high levels of salt (sodium chloride). Feedlot manure can contain up to 10 times the salt of normal manure and is especially likely to burn plants.

Watch out for Weeds!: Fresh manure from animals fed on pastures, hay, or wild vegetation can contain many weed seeds which can still germinate well after passing through the digestive system. Composting the manure first may generate enough heat to kill many of the weed seeds.

Suggested Application Rates for Manure

- Fresh or composted manure applied at 6-12 liters/sq. meter (a layer 6-12 mm or 0.25-0.5" thick) per crop planting should provide enough nutrients for good yields if the manure is of good quality and has been properly stored. This rate also supplies enough organic matter to achieve at least some improvement in soil physical condition.

NOTE: In soils very low in P, rates several times higher than this would be needed. In such cases, it's often better to supplement the manure application by applying a chemical fertilizer like superphosphate at planting or transplanting time. For long-term crops like vining (indeterminate) tomatoes, additional N sidedressings in the form of manure tea (to be discussed shortly) or chemical fertilizer may be needed.

- Fresh poultry and sheep manures are especially "hot" and shouldn't be applied at more than 6 liters/sq. meter.
- If plentiful or of poor quality, manure can be applied at rates several times the above, except in the case of very fresh manures which can burn seeds or seedlings or even cause nitrate pollution of nearby water sources, especially shallow wells. Excessive nitrate levels in drinking water can cause potentially fatal "blue baby" disease (methemoglobinemia) in infants (particularly those on water-mixed formula) and are also toxic to livestock.
- If manure is scarce, it's usually better to apply a moderate rate over a larger area than a high rate over a smaller area.

Some Handy Conversions for Manure Application

- One liter/sq. meter equals a layer one millimeter thick. Therefore, 6-12 liters/sq. meter equals a layer 6-12 mm thick (about 0.25-0.5").
- One shovelful of manure contains about 3-4 liters. Therefore, 2-4 shovelfuls will supply the recommended "ballpark" rate of 6-12 liters/sq. meter.
- One cubic meter of manure contains 1000 liters and will supply enough nutrients for about 80160 sq. meters of actual planted area (i.e. bed area alone, not counting alleyway area), if of good quality.
- One liter of fresh (wet) manure weighs roughly 1 kg. One liter of very dry manure weighs 0.3 kg (dairy and pig manures) or 0.6 kg (chicken manure).

Making and Using Manure Tea

Manure tea is a liquid form of fertilizer made by steeping a bag of manure in a drum of water for 24 weeks; the tea-like liquid can then be applied to growing crops or used as a starter solution during transplanting (refer to the vegetable section in Chapter 10). Recent research (summarized below) has shown that tea made from fresh manure contains good levels of most nutrients. As with manure, the tea probably contains some additional growth-promoting substances like hormones and B vitamins. Here's how to make and apply it:

NOTE: Manure tea can be made in smaller batches than used in this example.

- Fill a 50 kg burlap bag or other porous sack with fresh manure and tie it shut. (Fresh manure provides more readily-soluble nutrients than rotted manure, especially in the case of N.)
- Place the bag in a 55 gal (200 liter) drum and fill with water to the top. If necessary, weight the bag down with rocks to keep it submerged. Cover the drum to keep flies away and to prevent mosquitos from breeding. Let it stand for about 2 weeks.
- Given the many variables, application rates vary widely, and you'll have to experiment. Most recommendations say to further dilute the mixture with water to a weak brown color. Don't reuse the manure, but start with a fresh batch each time the drum is refilled. The leftover solids can be used as a soil conditioner but aren't likely to be a good nutrient source.

Recent Research on Manure Tea: Although manure tea has been used for centuries with good results, only recently has valid research been conducted with it. Below is a brief summary of trials evaluating the usefulness of chicken manure tea as a fertilizer carried out by a senior ag student at California Polytechnic University in San Luis Obispo. Note that the fresh chicken manure from well-fed birds used in this study has an especially high nutrient content compared to most other manures, and the same would be true of the resulting tea.

- Tea preparation: Fresh chicken manure was placed in a burlap bag at 3 rates (20, 35, 50 lbs.) and steeped in water in 35 gallon garbage cans for 4 weeks.
- Nitrogen content: Good levels of available N were obtained in the tea, almost entirely in the ammonium form (NH_4^+). With the 20 lb. bag, the tea attained about 85% of its maximum ammonium content (860 ppm in week 4) in the first week. For the 35 and 50 lb. bags, only about 50% of the maximum ammonium content (1514 and 1424 ppm respectively in week 4) was obtained the first week. The reason that the 50 lb. bag yielded less available N than the 35 lb. bag was probably because the higher manure rate depressed bacterial activity.
- Overall nutrient content: The tea from the 20 lb. bag was diluted with water by 4-fold (1 part tea, 3 parts water) after 4 weeks, and its nutrient content was compared to that of a standard hydroponic growing solution (i.e. where all nutrients must be supplied by the solution itself). The diluted tea's N, P, K, and zinc levels compared favorably with the solution; other nutrients would need to be supplied by other sources (e.g. soil, manure, compost, chemical fertilizer).
- Plant growth: Greenhouse trials were conducted to compare the diluted tea and a hydroponic solution when applied to tomatoes grown on 3 different mediums: sand, redwood chips, and redwood sawdust. In all cases the tea-fed plants performed almost as well as those receiving the chemical solution, despite the supposed lack of several nutrients. It is likely that the missing nutrients were supplied by the growing medium. It was calculated that each tomato plant used about 4.5 gallons of tea (equal to 1.4 lbs. poultry manure during the 3 month trial period).

Compost Tea: Making a similar tea out of compost has been recommended; however, it wouldn't seem to be as effective since more of the nutrients in compost are in the insoluble, organic form and would take longer to leach into the tea. You may want to experiment with this, however.

Compost

WHAT IS COMPOST?

Compost is organic matter such as crop residues or manure that has been fairly well decomposed (usually in a pile or heap) and is well on its way to becoming the dark, crumbly stuff called humus.

WHAT IS COMPOST MADE OF?

It can be made from almost any waste organic matter such as:

Crop residues: Maize stalks, rice straw, leaves, etc.

Natural vegetation: Weeds, grass, tree leaves.

Manure

Some materials that shouldn't be used: Human feces (urine is OK), dog and cat manure are likely to contain parasites and disease organisms that can be passed to humans. Although a well-managed compost pile should generate enough heat to kill these bad guys, most piles fall short of this, mainly because of insufficient nitrogen and lack of periodic turning. Pig manure can be composted but probably shouldn't be used on crops whose edible parts are in contact with the soil. Likewise, vegetation showing signs of plant diseases should be avoided, except under ideal composting conditions. Meat scraps or dead animals are sure to attract flies and rodents.

HOW DOES COMPOST COMPARE WITH MANURE?

Like manure, compost is a low-strength, slow-release fertilizer. In fact, compared with fresh manure, its nitrogen is in a more stable form and not susceptible to loss as ammonia gas. As with well-rotted (composted) manure, compost won't "burn" seeds or seedlings.

Nutrient value: Like manure, the nutrient value of compost varies a lot and depends on what it's made from (see Table 8-4). Aside from N, P, and K, it also supplies varying amounts of secondary nutrients and micronutrients. As with manure, compost contains other growth-promoting substances such as B vitamins, natural hormones, and organic acids. Compost that has been made from a variety of materials is likely to provide the best spectrum of nutrients.

TABLE 8-4

Common NPK Ranges for Composts

Nutrient Percentage Kg of Nutrient per 1000 kg of Compost

N 0.75-1.5% 7.5-15 kg

P₂O₅ 0.25-0.5% 2.5-5 kg

K₂O 0.5-1.0% 5.0-10 kg

Composting First vs. Adding Fresh Materials Directly to the Soil

Adding fresh manure or plant residues directly to the soil usually ends up adding more nutrients and humus than composting these materials first. Losses of N as ammonia gas can be high during composting, especially when fresh manure is used. However, there may be some advantages to composting the materials first:

- Although some studies have shown that composted manure provides only about half as much readily-available N compared to adding the same manure in fresh form, it's less likely to burn plants and also supplies N over a longer period due to its slow-release nature.

- The composting process reduces the material's volume by about half, meaning there's less hauling to do.
 - Fresh manure can be mixed and composted with low-N materials such as straw and rice hulls and will supply the needed N to break them down more quickly; such mixing will also reduce the loss of N as ammonia gas from the fresh manure during the composting process.
 - A well-made and properly turned compost pile will generate enough heat to kill the weed seeds contained in the fresh manure from animals fed on pasture, hay, or wild vegetation.
- SOME POSSIBLE LIMITATIONS OF COMPOSTING

Like manure, composting is more practical for small plots because:

- It requires a lot of hand labor.
 - It requires a lot of water to keep the pile moist during the 1-4 months of composting, which may be a problem during the dry season.
 - Most farmers won't have enough compostable materials to meet their needs. Crop residues like millet and sorghum stalks are often fed to livestock or used for fencing or building materials. Also, it's usually much easier, and may be just as beneficial, to leave them on the soil surface in the field.
 - Shrinkage of the pile, which averages about 50%, can be discouraging. Part of this is due to settling, but most of it results from the activities of fungi and bacteria that digest the material, converting much of its carbon to carbon dioxide gas.
- Composting is usually best suited to a farmer's smaller plots and to communal garden projects. It's especially feasible for school garden projects where there's lots of labor available.

WHAT GOES ON IN A COMPOST PILE?

Compost results largely from the activities of various kinds of fungi and bacteria that feed on the materials in the pile and gradually convert them into humus. Insects and earthworms are also found in compost piles, especially at the latter stages of decomposition, and aid in the process.

NOTE: Composting is ordinarily an aerobic process involving microbes that require oxygen; although it's also possible to make compost anaerobically (without oxygen), this section focuses on the more common aerobic process.

Heat buildup in the pile: A properly made pile will heat up to about 65-70°C (150-160°F) within 2-4 days due to the action of thermophilic (heat loving) bacteria. The pile will gradually cool down as other types of fungi and bacteria take over. During the first several weeks, the pile will usually reheat somewhat each time it's turned.

FACTORS INFLUENCING THE SPEED OF COMPOSTING

Under the most ideal conditions, you can make compost in just 10-15 days, but few limited-resource farmers or gardening projects will be able to do this. More likely, it will take 2-4 months. This is because it's very difficult to meet the 5 essential requirements for rapid composting. These are:

- Finely shredded material.
- An adequate carbon:nitrogen ratio
- Adequate moisture.
- Adequate aeration.
- Self-insulation

An understanding of these 5 essentials is very helpful in learning how to make compost successfully and will also give you an idea of how long the process may take in your situation. Let's look at each requirement in detail.

- **FINELY-SHREDDED MATERIAL:** Pieces 6 mm (1/4") or smaller are essential for rapid composting, because they provide much more surface area for the microbes and insects to work on. This isn't likely to be practical without a shredder. (Hand-cranked shredders are available in some countries but may produce larger pieces.) Rather than spending a lot of time hand-chopping, it's better to settle for larger pieces and a slower composting process. However, even coarsely-chopped material will make the pile much easier to turn.

- **AN ADEQUATE CARBON: NITROGEN RATIO:** The fungi and bacteria need the right diet to function efficiently. They need carbon for energy, and they need nitrogen for growth and multiplication. (They convert the N into protein.) A C:N ratio of about 20-30:1 is ideal, but most materials contain more carbon and less nitrogen than this. Here are some useful guidelines for distinguishing between high-N materials (those with a narrow C:N ratio) and low-N materials (those with a wide C:N ratio):

LOW-N MATERIALS: Any old, brown or yellow, fibrous vegetation like maize-sorghum-millet stalks, rice straw, old grass with seed heads, rice hulls, peanut hulls, old dry leaves, sawdust. The yellower or browner and the older the material is, the lower its likely N content.

Examples: Sawdust has a C:N ratio of about 500:1 and straw ranges from about 50:1 to 130:1; maize, sorghum, and millet stalks (at harvest time) have a C:N ratio of about 60:1.

HIGH-N MATERIALS: Young, soft, green vegetation, especially from legumes, is likely to be a good N source. Fresh manure, especially poultry manure, that has been protected from the elements and that doesn't contain too much strawy bedding is an excellent N source.

Examples: Fresh manure has a C:N ratio of about 15-20:1, strawy manure 50:1, fresh young grass 15:1, green legume leaves 12:1.

Some General Guidelines for Getting the Right C:N Ratio: There's no way to be exact, and luckily you don't have to be. However, piles with too little N will take longer to break down and will shrink more, too, as the microbes try to burn off the excess carbon (as carbon dioxide) to narrow the C:N ratio to their liking. Surprisingly, it's not a good idea to have too much N in the pile, either, because the microbes will convert the excess N they don't need into ammonia gas which is lost to the air. Your best bet is to "guestimate" an appropriate mixture of high-N and low-N materials, based on their likely C:N ratios. The more low-N materials used, the greater the need for high-N materials. Here are some approximate "recipes":

- 1/3 low-N materials (straw, peanut hulls, etc.) + 2/3 high-N vegetation (young and green)
- 1/2 low-N materials + 1/2 high quality manure
- **ADEQUATE MOISTURE:** The compost microbes need moisture to thrive. An adequately moist pile should contain about 50-60% moisture and should feel about as wet as a cloth towel that has been wrung out after being immersed in water. When lightly squeezed, the material should leave a film of moisture on your hand. However, excessive water will lower the pile's oxygen content or it may drain out the bottom, carrying nutrients with it. Since the pile's heat production speeds up moisture evaporation, it will need periodic rewetting, especially in the early stages. Compost made in covered pits (see below) loses less moisture.
- **ADEQUATE AERATION:** The fungi and bacteria involved in the typical aerobic composting process require oxygen to thrive. Two practices are essential to avoid oxygen deprivation.

- Avoid over-compacting the pile while building it, especially if it's made from lots of green, succulent material or wet manure.
 - Turning the pile periodically is the best way to maintain adequate oxygen. The more often the pile is turned, the more quickly it will fore compost. For rapid composting (10-15 days), you'd need to turn the pile at least twice a week (aside from using finely shredded material) which maybe too laborious. You can also try placing vertical poles in the pile during building and then withdrawing them to leave air channels. For piles that won't be turned, it's possible to introduce earthworms into the pile after the initial heating has subsided, (Don't turn the pile afterwards or it may reheat and kill them.) The earthworms usually multiply rapidly and will help aerate and mix the pile.
 - **SELF-INSULATION:** The pile should be large enough to hold the heat in. A good minimum size (before shrinkage) is about 2 cubic meters (i.e. a square-shaped pile measuring about 1.25 meters on a side or a cone-shaped pile measuring 2 meters in diameter at the base and 2 meters tall).
- HOW TO MAKE COMPOST**

Now that you understand the basic principles of composting, let's talk about how to actually make compost. We'll cover several methods:

- Compost piles: above-ground stacks, below-ground pits.
 - In-the-bed basket composting for gardens.
 - Direct-composting and mulch-composting
- Two Types of Compost Piles: Stacks and Pits

Stacks: Above-ground piles work well in the wet season or where there's enough readily available water for periodic rewetting. (See Figure 8-2.)

Pits: Below-ground pits reduce water evaporation losses and are well suited to the dry season or in cases where nearby water is scarce. They shouldn't be used where the water table is shallow or they may end up being flooded. Some other guidelines:

- If you dig 2 pits next to each other, the compost can be easily and effectively turned (aerated) by moving it from one pit to the other.
- With 3 pits, you can maintain 2 separate piles and also turn them. (See Figure 8-1.)
- Pits with sloping sides make turning and removal much easier.
- Building a shade structure over the pit or covering it with straw, palm leaves, or plastic will further reduce water losses.
- **Aeration needs of Pits:** Pits are more likely then stacks to run short on oxygen and usually require more frequent turning, especially if deeper than 75 cm.

FIGURE 8-1: Making compost using the pit method. With 3 pits it's possible to maintain 2 separate compost piles and turn then by alternately transferring them back and forth into pit B.

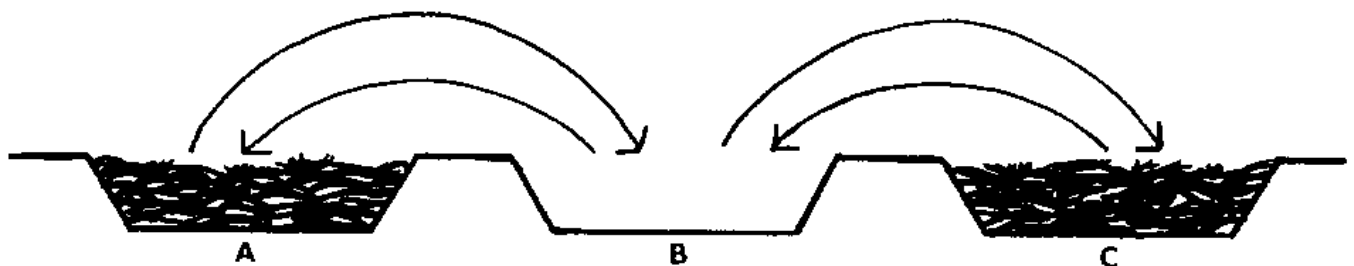


FIGURE 8-2: An above-ground compost pile (stack).



How to Make and Maintain Compost Piles (Stacks or Pits)

- An especially good location for a compost pile is under banana or other fruit trees. They'll provide shade (for people and the compost) and will reap any benefits from nutrients that leach out if excess water seeps from the pile.
- When using several different materials, it's a good idea to add each material as a separate layer to keep track of the relative amounts being added. Another way is to make separate stacks of the different materials in the approximate proportions needed and then combine them to build the pile.
- Add water (if needed) as the pile is being built up. The material is wet enough if it leaves moisture on your hand when lightly squeezed. (It shouldn't be so wet that you can actually squeeze water from it, however.) Too much water may cause poor aeration or leak out the bottom and carry away nutrients. Wet manure and fresh, green material may require little or no added water.
- Mix up the pile well to combine the different materials. This is important so that low-N and high-N materials can be mixed together to provide a good carbon: nitrogen ratio for the bacteria and fungi. (Some garden references imply that the layers should remain intact, but this isn't correct).
- Avoid over-compacting the pile since this reduces aeration.
- To reduce water loss in dry season stacks, cover the outside of the pile with insulating material like millet stalks, straw, or plastic (see Fig. 8-2).
- Where stacks are used during high-rainfall periods, excess water can be avoided by making them cone-shaped and/or covering the outside with stalks or plastic. (If using plastic, the pile may require more frequent turning to insure good aeration.)
- How to turn a pile: Try to turn it "inside-out" so that the outer layer ends up on the inside and vice-versa. This will help assure a good kill of weed seeds and possible pathogens by exposing all the material to high temperatures in the pile's interior.

Some Other Guidelines for Compost Piles

- Is soil needed?: Some sources suggest that soil should make up as much as one third of the pile in order to supply needed microbes. However, studies have proven that manure or fresh, green material will supply all the microbes needed. Soil adds a lot of unnecessary weight to the pile, too.
- One appropriate use of soil: In cases where the pile has an excess of high-N materials, ammonia gas (82% N) will be given off. If this occurs, N losses can be reduced by covering the pile with 4-5 cm of soil or by mixing soil into the pile; this will help trap the ammonia gas and convert it to stable ammonium. However, adding more low-N materials like straw or sawdust to the pile is just as effective.
- Use of lime or wood ashes: It used to be thought that this would help speed up the process and keep the pile from becoming too acid. Now it's known that lime is rarely needed unless lots of very acid materials like pine needles or oak leaves are used. Wood ashes should only be used in small

amounts since they are a potent liming material and may end up raising the soil pH too high if large amounts of ash-laden compost are applied. A high pH in the pile itself will increase losses of nitrogen as ammonia gas during composting.

- Use of N fertilizer: It can be added to narrow the C:N ratio of low-N compost piles that lack enough high-N organic materials. However, this is an expensive use of chemical fertilizer, and you may be better off looking for organic sources or settling for a slower process. A ballpark rate for N fertilizer is the equivalent of 100150 cc of urea (45% N) per sq. meter of pile per 20 cm layer (500750 cc of urea per cubic meter).

- Use of compost “starters”: Despite advertising claims, these commercial liquids or powders containing microbes and nutrients have proven to be of no significant value in properly made piles. However, recent research in India has shown promising results from inoculating rice straw compost piles (very low in N) with fungi and N-fixing microbes; the treated straw composted 4 weeks faster and yielded 3 times as much humus (probably due to the carbon-saving effect of the N-fixing microbes).

Troubleshooting Faulty Compost Piles

Failure to heat up: The most likely cause is insufficient N or perhaps not enough moisture in the pile. Lack of oxygen is unlikely to be the problem, because piles will contain enough air for at least an initial heat buildup unless they have been overly compacted. Oxygen deficiency is more likely to be a problem in compost pits.

Ammonia smell: Caused by too much N in the pile. Mix in some low-N materials like straw or rice hulls or try covering the pile with a layer of moist soil to trap the ammonia.

Foul odors: Indicates anaerobic conditions (too little air). The remedy is to loosen up the pile by adding coarser materials and to turn it daily until the odor disappears.

When is Compost Ready for Use?

You don't have to wait until the pile has completely broken down into fine crumbly material. It's ready to use once it's reached a semi-rotted stage where the materials are no longer distinguishable. They'll continue to decompose in the soil.

How to Apply Compost

Compost is applied in much the same way as manure and rates are similar. (Refer to the previous section on manure.) It can also be used as a mulch when plentiful. Unlike fresh manure, compost can be left on the soil surface without losing nitrogen as ammonia gas. (However, anaerobically composted material contains about half its N in the ammonium form and is prone to ammonia gas losses unless mixed into the soil.) As with manure, very high rates of may be needed to supply enough P on soil's low in this nutrient. In this case, it may be better to use compost in combination with a chemical fertilizer such as superphosphate (see Chapter 9).

SOME OTHER COMPOSTING METHODS

Basket Composting in Vegetable Beds

Basket composting is being used by vegetable gardeners in the Philippines where it was popularized by the Mindanao Baptist Rural Life Center. In this method, compostable material is placed in half-buried baskets located right in the garden beds where it forms compost (see Figure 8-3). Crops like peppers, okra, tomatoes, squash, and yardlong beans are planted around the baskets. All the watering is done through the baskets to move the nutrients out into the soil and encourage crop roots to enter the baskets. Where suited, basket composting is more likely to be adopted than usual composting methods for several reasons.

- It takes less work, because no turning is needed and materials can be added bit by bit.
- Instead taking 2-4 months, basket compost begins to be usable by plants as soon as the materials begin decomposing.

The method is best adapted for garden plots in areas where there's a good supply of green vegetation or manure, since such materials break down relatively quickly. You can modify this method to suit local conditions, but here are some general guidelines for making basket compost:

- The baskets act as containers for the composting material and should be at least 30 cm in diameter and 30 cm tall. Place them about 1 meter apart in holes so that about half their height is buried. If old baskets aren't available, place sticks in a circle and then weave palm thatch, etc. around this framework to form a basket.
- Place the most decomposed materials in the bottom of the baskets and the newer ones at the top; that way the crop roots will be able to utilize the nutrients more quickly and you can plant or transplant around the baskets right away.
- If the materials are fresh, wait 2-3 weeks before planting or setting plants around the baskets to allow time for some breakdown and nutrient release to occur.
- Apply all garden water through the baskets themselves to help move the nutrients into the soil and encourage plant roots to enter the buried portion of the baskets.
- After harvest, remove the baskets' contents and work them into the surrounding soil.



Mulch -Composting

Some organic materials like ipil-ipil (*leucaena*) leaves and rice hulls make good mulches. They can be applied over the soil surface and eventually worked into the soil as they break down. If used by themselves, low-N materials such as rice hulls and sawdust may cause a temporary N deficiency if worked into the ground before they have rotted enough, unless additional N is supplied.

Direct-Composting (Sheet-Composting)

Don't forget that fresh organic wastes can also be added directly to the soil where they'll eventually become compost. However, you may find that adding a lot of fresh vegetation to the soil interferes with vegetable seedbed preparation and planting. Adding low-N materials alone may cause a temporary N tie-up unless an additional source of N is applied.

Green manuring and cover-cropping

Green Manuring vs. Cover-cropping

These terms are often used interchangeably, but there are some distinctions.

Green Manuring: This is the practice of planting a crop for the purpose of improving the soil. Instead of being harvested, a green manure crop is incorporated into the soil (i.e. turned under), usually while still green and immature, where it decomposes. The crop is closely sown (usually broadcast), as the main aim is to produce the maximum amount of green material. Green manuring can add a lot of organic matter to the soil. If the crop is a legume like cowpeas, considerable nitrogen may be added, too. A green manure crop can also function as a cover crop during growth by protecting the soil from erosion by wind and rain.

Cover-Cropping: This is the practice of planting a closely-sown crop mainly to protect the soil between normal cropping periods. Cover crops can also be planted between trees in orchards. In some situations, it's also possible to saw a cover crop between the rows of a maturing crop such as maize. Cover crops are often eventually turned under as green manures; however, unlike normal green manuring where the crop is usually turned under 40-90 days after planting, cover-cropping often takes place over a longer period, because its main purpose is soil protection. In fact, a cover crop may even be eventually harvested or periodically cut or grazed over a number of

months.

The Benefits of Green Manuring and Cover-Cropping

- Green manuring can produce a lot of valuable organic matter in a short period, often with little cost and labor.
- If a legume is used, green manuring can add appreciable N to the soil due to N fixation.
- In addition, other nutrients may be “mobilized” by being taken up by the green manure and released in a more available form when the crop is turned under; however, unlike in the case of nitrogen, there is no net addition to the soil.
- Unlike compost and manure, green manuring is also well suited to large plots, although a plow, harrow, or considerable hand labor are needed to turn under a green manure crop.
- Both practices protect the ground from water and wind erosion.
- They act as “holding tanks” by absorbing nutrients and preventing them from being lost from the root zone by leaching (especially a problem with N).
- They suppress weed growth through shading and competition.
- They also can provide some good-quality forage for livestock (especially when legumes like cowpeas or kudzu are used) or food for people.
- Some green manure or cover crops can be intercropped with cereal grains to help suppress weeds. (More on this below.)
- Two legume green manure/cover crops, *Crotalaria spectabilis* (showy crotalaria or rattlebox) and *Indigofera hirsuta* (hairy indigo) have proven to be effective in reducing the populations of harmful soil nematodes that attack crop roots. (Note that the seeds of all crotalaria species, as well as the leaves of *Crotalaria spectabilis* and *C. juncea*, are poisonous to livestock.)

The Fertilizer Value of Green Manure Crops

Nitrogen: Only legume green manures will add new N to the soil, and the amount added varies greatly with the species, length of growing period, soil N content, and other factors:

- The amount of new N produced is often overestimated, because not all the N in a legume comes from N fixation; some comes from the soil itself. Research has shown that the proportion of N derived from fixation can range from 30-80% and is largely dependent on the soil's content of available N. The higher the level of available N (nitrate and ammonium) in the soil the less N the rhizobia bacteria will fix (they become “lazy”), and the less net N added to the soil.
- When grown as short-term green manures (40-50 days), legumes like cowpeas and mungbeans will return about 40-60 kg/ha of N. When grown as longer-term green manures (90 days), forage legumes like stylo and kudzu will return about 100-200 kg/ha of N. In both cases, the amount of net N added (i.e. that due to fixation) will be roughly half these amounts. This means that additional N may be needed in some cases for moderate to high yields of a non-legume crop that follows a legume green manure.
- Temperate-zone research has shown that roughly half of the legume's N becomes available to succeeding crops in the first year, but this figure is likely to be much higher in the tropics, given the more rapid breakdown of organic matter at higher temperatures.

Other Nutrients: Although legume green manures can add appreciable new N to the soil, it's important to realize that neither legume nor non-legume green manures will add new amounts of other nutrients when turned under “in place”, since these nutrients are derived from the soil alone.

However, if green manure crops are cut and carried to other plots, they will enrich that land with nutrients by transfer, especially if concentrated on a smaller area.

Are Green Manuring and Cover-Cropping Feasible for Third World Small Farmers?

Despite the apparent advantages of green manuring and cover-cropping, they're not always feasible for Third World small farmers. Compared to North America and Europe, there's been much less experience and research in this area in most developing countries. Crop selection and timing can be very location-specific. Here are some other points to consider:

- Green manures and cover crops often fit in better with the cropping systems of the humid tropics where there's more of a year-round growing season. In the wet-dry or semiarid tropics with long dry spells, crop scheduling is often very tight. Farmers may not be able to fit in green manures or cover crops and still produce their normal ones. Even where irrigation is available, it's often more cost effective to use it for cash crops.

NOTE: A great opportunity for green manuring occurs during the wet season in dry season gardens which often aren't cropped during the rainy months.

- In drier areas, they may seriously deplete the soil moisture needed for a succeeding cash or staple crop.
- Under tropical conditions, the increase in soil humus from turning under a green manure crop may be short-lived, because organic matter breaks down much more quickly in warm temperatures. On the other hand, this means that the green manure's N will become more quickly available.
- Turning under a non-legume can sometimes cause a temporary deficiency of N, P, or sulfur, especially if done at an advanced stage of growth when the carbon: nitrogen ratio widens. Legume vegetation generally contains twice as much N as non-legume vegetation (particularly at later stages) and breaks down quickly to release these nutrients. (See Chapter 6 for an explanation of this type of tie-up.)

USING GREEN MANURE AND COVER CROPS

For the most relevant information for your specific areas, check with the local ag extension service. If there's an ag experiment station in your agro-climatic zone, it would be well worth a visit to see what work is being done in this area. Here are some general guidelines:

Choosing a Green Manure or Cover Crop

Some common green manure and cover crops in temperate areas are Austrian winter peas, crimson clover, broad beans (fava beans), winter vetch, oats, winter wheat, and annual ryegrass. However, they aren't adapted to tropical regions. Sudan grass, sorghum-sudan grass, and pearl millet are some non-legumes that are adapted to both the tropics and to summer production in temperate zones. Legume green manure and cover crops adapted to the tropics and subtropics are listed in Table 8-5 and described in more detail in Appendix F.

Legumes vs. Non-Legumes: Farmers are usually better off using a legume for a green manure, since it can add considerable new N to the soil. In addition, there's little likelihood of causing a temporary tie-up of N, P, or sulfur as can sometimes occur when a non-legume is turned under, especially at an advanced stage of growth. However, where there is a need for a long-term cover crop, grasses or grass-legume mixes can be very appropriate.

Using Weeds: In some cases, it may be advantageous in terms of seed cost, adaptation, and availability to use a naturally-occurring weed as a green manure, especially if it's a legume. In fact, some of the legumes listed in Table 8-5, such as crotalaria and coffeeweed, are also weeds. However, care must be taken in the selection and management of such plants to avoid their truly

becoming weeds. Don't use species that propagate by hard-to-eradicate runners, and never allow the crop to produce seed. (In fact, many weeds have the ability to continue maturing their seeds, even when cut down at the early seed head stage.)

Here are some other important criteria to consider when selecting a green manure or cover crop:

- Adaptation to the area in terms of climate, soils, insects, diseases, and nematodes.
- It should take relatively little cost, labor, and skill to establish and manage. Remember that green manure and cover crops are closely sown, which requires a large number of seeds per area. Due to their large seed size and demand as a food crop, pulses (edible grain legumes such as cowpeas) may be too expensive or scarce to be used as soil improvers (from 60-120 kg/ha of seed is needed. Small-seeded, non-food legumes (e.g. crotalaria and centrosema) have many more seeds per kilogram and thus require lower seeding rates (about 4-20 kg/ha); seed cost per kilogram may be lower, too.
- Quick growth, especially in the case of short-term green manuring that's sandwiched in between crops or where rapid erosion protection is needed.
- Ease of eradication, in the case of short-term use. Some perennial tropical grasses (e.g. bermuda grass, pare grass, and kikuyu) propagate by runners and can become invasive and difficult to eradicate. Some perennial tropical legumes like centrosema are vigorous, vining growers best suited to long-term use.

TABLE 8-5

SOME LEGUMES FOR GREEN MANURING OR COVER-CROPPING IN TROPICAL AND SUBTROPICAL REGIONS

(See Appendix F for a description of each legume and its adaptation).

I. Quick-Growing Legumes for Short-Term Use (40-80 days)

Scientific Name Common Names

Glycine max Soybean

Phaseolus aureus Mungbean, green gram

Phaseolus acutifolius Tepary bean

Sesbania exaltata (*S. macrocarpa*) Sesbania, coffeeweed

Vigna unguiculata (*V. sinensis*) Cowpea

II. Bush or Viny Legumes Best Suited for Long-Term Use (90 days or more)

Scientific Name Common Name

Calopogonium mucunoides Calopo

Canavalia ensiformis Jack bean

Canavalia gladiata Sword bean

Centrosema pubescens Centrosema, centro

Clitoria ternatea Butterfly pea

Crotalaria spectabilis Showy crotalaria

Desmodium intortum Greenleaf desmodium

Desmodium uncinatum Silverleaf desmodium

Dolichos lablab Hyacinth (lablab) bean

Indigofera hirsuta Hairy indigo

Phaseolus atropurpureus Siratro

Phaseolus lathyroides Phasey bean

Pueraria phaseoloides Tropical kudzu, puero

Stizolobium spp. (Mucuna spp.) Velvet bean
Stylosanthes gracilis (guyanensis) Stylo
Stylosanthes humilis Townsville stylo

III. Legume Trees or Shrubs for Cut-and-Carry Green Manuring

Scientific Name Common Names

Cajanus cajan Pigeon pea
Calliandra calothyrsus Calliandra
Gliricidia sepium Madre de cacao
Leucaena leucocephala Leucaena, ipil-ipil
Mimosa scabrella Bracatinga
Sesbania bispinosa Prickly sesban
Sesbania grandiflora Sesbania
Sesbania sesban Sesban

Fertilizing Green Manure Crops: Legume green manure crops should require no nitrogen if the proper strain of rhizobia bacteria is present or added by inoculating the seed (see Chapter 10 under "Pulses"). However, legumes often benefit P and K applications on low-fertility soils. On low-P soils high P tie-up capacity, it may be wise to row-plant the green manure so that the P fertilizer can be band-applied to minimize tie-up.

When to Turn Under Green Manures

If the purpose is to produce the maximum amount of organic matter (or N) in the shortest amount of time, it's best to turn under quick-growing annuals like cowpeas or mungbeans about 40-50 days after sowing; this usually corresponds to the flowering stage in these legumes. Waiting longer will produce more added nitrogen but little extra green material, since the crop's energy is diverted into seed production. However, it may be advantageous to continue growth for cover-cropping purposes. Perennials such as tropical kudzu, stylo, and centrosema are slower growing and usually require 90 days or more to produce sufficient vegetation.

Avoiding toxicity problems: In order to avoid possible seedling injury due to toxic decomposition products, green manure crops should be turned under at least 2-3 weeks before planting the next crop.

What about seed harvesting?: If a legume like cowpeas or beans is grown to maturity for seed harvest (hard, dry seed stage), much less N will be added to the soil when the crop residue is turned under. That's because about 75% of the N (as well as 75% of the P and 60% of the K) in the plants eventually ends up in the mature seeds themselves. Another consideration is that green manure crops are usually sown more densely, which discourages good grain yield.

What about growing legumes among non-legumes to supply nitrogen?: When a legume like beans is interplanted with maize (both for harvest), very little of the legume's N is transferred to the non-legume for 2 reasons. First, most of the N fixed by the legume ends up in the seeds. Second, very little N is excreted into the soil by legume roots or nodules during growth, although there are 2 important exceptions:

- Among the grain legumes, mungbeans (*Phaseolus aureus*) have the unusual ability to excrete significant amounts of N (up to 40-50 kg/ha) into the soil during growth. Such N can be utilized by a companion crop.
- Most pasture legumes (e.g. clovers, siratro, and stylo) excrete enough N to satisfy the needs of the pasture grasses with which they are often grown in combination.

The Cut-and-Carry Method of Green Manuring

Legume trees and shrubs, such as leucaena and Gliricidia, can be used for green manuring by periodically cutting their branches and carrying them to an adjacent crop (in the case of alley-cropping) or to another field where they can be either worked into the soil or used as a mulch. Leucaena leaves contain 0.5-1.0% nitrogen on a fresh-weight basis. It's estimated that 400-600 kg of N yearly can be supplied by the foliage obtained from one hectare of leucaena cut back to 1 meter in height every 3 months. (Remember that not all this N is derived from N fixation, however). The fresh weight of the harvested foliage would be roughly 40,000-80,000 kg/ha. The cut and-carry method requires considerable labor, and care must be taken to replenish soil nutrients (other than N) taken up by the green manure crop.

Some Examples of Successful Green Manuring and Cover-Cropping in the Tropics

- The National Maize Program (PNM) in Zaire has been using 2 legumes, crotalaria (toxic to livestock) and soybeans as green manure/cover crops. In this case, the crotalaria has proven superior to soybeans in N production and has supplied all the N required for high maize yields. One problem is that most legumes won't do well on Zaire's low-phosphorus soils (common in the tropics) without additional P as chemical fertilizer.
 - In parts of S.E. Asia, green manuring between rice crops using legumes is common. In one trial in the Philippines, rice yields were more than doubled (3600 kg/ha vs. 1500 kg/ha) when any of the following green manure crops were used: cowpeas or mungbeans plowed under 45 days after seeding; stylo or tropical kudzu plowed under 90 days after seeding.
- Mulching

Mulching consists of covering the soil surface with a layer of organic matter (or plastic or newspaper) and can have many benefits. Mulching:

- Reduces soil water loss due to evaporation from the surface.
- Suppresses weeds. (However, perennial weeds like nutsedge may be able to grow through mulches, including plastic.)
- Protects the soil from water and wind erosion.
- Modifies soil temperatures. (See below.)
- Keeps vegies like cucumbers and tomatoes from ground contact to reduce rotting.
- Encourages earthworms (see next section).
- "Organic" mulches like hay add humus to the soil as they decompose.
- Can be used between planting and seedling emergence to keep soil moist and prevent seed washout. (See Chapter 4 on seedbed preparation.)

Under some conditions, mulching can have disadvantages:

- Organic mulches may attract pests like crickets, ants, slugs, snails, and even termites.
- In cool regions, organic mulches may actually keep the soil too cool for good growth of warm-season vegetables like okra, eggplant, and the squash family.
- In hot regions, plastic mulches may overheat the soil, especially when clear plastic is used.
- In wet areas, organic mulches may encourage stem rots. Keeping it 7-10 cm away from the stems will help.

- Low-nitrogen organic mulches like sawdust and rice hulls may cause a temporary N tie-up if they are worked into the ground before they have decomposed adequately. Although the University of Hawaii recommends mixing the equivalent of 350 cc of urea (45-0-0) into each 100 100 liters of sawdust, this shouldn't be necessary if the sawdust mulch is kept on the soil surface.

The Effect of Mulches on Soil Temperature

- Organic mulches like straw help cool the soil, and generally reduce soil temperature fluctuations; this can be beneficial for cool-season crops like lettuce and cabbage when grown in overly hot weather.
- On the other hand, plastic mulches warm the soil if clear or dark colors are used. Clear plastic can increase soil temperatures in the upper 10-12 cm by as much as 10-12°C (18-22°F), and black plastic by about 3-6 °C (5-10°F). This may be desirable for warm-season crops like eggplant and squash when grown in overly-cool weather but may produce harmfully high soil temperatures in hot weather unless the mulch is well shaded by the crop's foliage. (It's also possible to cover the plastic with an organic mulch during the hot season.)
- White or reflective plastic will cool the soil and reduce soil temperature fluctuations by 3-6°C (5-10°F).

WHEN AND HOW TO MULCH

Situations Where Mulching may be Beneficial

As shown above, mulching can be beneficial in both dry and wet regions. In fact, the PATS ag trade school in Ponape, Micronesia uses mulch successfully on raised beds in clayey soils under 4500 mm (190") annual rainfall. (They use baits to control slugs attracted to the mulch.) Likewise, dry season vegetable gardens in areas like the Sahel will often benefit from mulching. Mulching can also be used on a larger scale for field crops. In experiments done by IITA (International Institute for Tropical Agric.) in Nigeria, mulching increased maize yields by 23-45 percent and greatly reduced the labor needed for hand weeding which accounts for 50-70 percent of total labor there. (In this case, the mulch consisted of crop residues and weeds killed with a herbicide.) Coconut yields on Pacific atolls have been increased by 100-200% by using cut undergrowth as mulch, rather than burning it, although extra labor is involved.

How to Use and Apply Mulches

Pre-emergence mulches: Applying a pre-emergence mulch to the soil after planting helps maintain good soil moisture for germination and prevents the seeds from being washed out by heavy rain or careless watering; it can also reduce soil crusting problems that adversely affect seedling emergence. Straw or newspaper work well but must be removed as soon as seedlings start emerging or they will quickly become spindly and weak due to lack of sunlight. However, in some cases, pre-emergence mulching attracts harmful insects and even termites. You can also try a "grow-through" mulch of light, fine material like rice hulls or sawdust which doesn't require removal.

Post-planting mulches: Mulch can be applied shortly after the crop comes up. Where crickets and slugs are a problem, it helps to keep the mulch 7-10 cm away from the plants, at least when they're young; this will also help avoid stem-rot problems encouraged by high moisture. Fine materials like rice hulls can be applied about 4-6 cm thick (more is OK too). Coarser mulches like straw need to be applied at least 8-10 cm thick or they may admit enough sun to encourage evaporation and weeds. A newspaper mulch 2-4 pages thick works well but needs to be held in place with soil or rocks. Plastic sheeting for mulching can be as thin as 1 mil (.001"), especially if it is the embossed type that is stronger and more flexible than the smooth kind.

Earthworms

How They Help the Soil

- Earthworms eat soil in order to burrow and to feed on its organic matter. Though their excreted "castings" contain only the nutrients in the consumed soil, this digestion process speeds up the release of available nutrients from organic matter. They're also a good soil conditioner and stimulate beneficial soil microorganisms.
 - They mix and redistribute organic matter; under favorable conditions, they'll transport up to 4 kg of soil to the surface per sq. meter per year.
 - Earthworm channels improve soil aeration and drainage.
- Can Earthworms Turn a Sick Soil into a Healthy One?: A soil with lots of earthworms is usually a very productive one, but it's not a simple matter of cause and effect. Adding them to a poor soil is likely to get you nowhere. They won't survive, let alone thrive, unless the soil is in fairly in fairly good shape to begin with! The best approach is to promote their natural buildup by good soil management. Earthworms need many of the same conditions as plants do in order to prosper.

How to Promote Earthworms in the Soil

- Adjust soil pH if necessary; earthworms don't like very acid soils (below pH 5.5).
- Add lots of organic matter.
- Mulching helps by keeping the soil moist and adding organic matter.
- Good soil drainage is important.
- Overly-high rates of chemical fertilizers will discourage earthworms due to salt buildup; however, there's no evidence that reasonable rates are harmful.
- Some insecticides and herbicides that are applied to the soil are toxic to earthworms.

Using Earthworms for Composting

Under the right conditions, earthworms will consume and digest almost any nontoxic organic waste such as manure, crop residues, kitchen wastes, and even paper and cardboard. The end product is essentially compost. One method of making compost with earthworms is to raise them in wooden-sided beds about 30 cm deep or in shallow pits (with gravel in the bottom for drainage) filled with organic matter. Most fresh manures should first be allowed to partly decompose in order to prevent excessive heat. It will take a month or two for the worms to compost the material. Be sure to keep the beds moist, though not sopping wet. Occasional turning may be needed to prevent the material from compacting.

Earthworm compost can be made from rabbit droppings right under the hutches, using bins or shallow pits. A starter mix of 1/2 droppings and 1/2 fine compost gets them off to a good start. Some lime may be needed to counteract the manure's initial acidity.

Earthworms as Feed: They're very high in protein (about 70% on a dry weight basis) and have been successfully used for poultry feeding.

Chapter 9: Using chemical fertilizers

This chapter will give you a strong grounding in the use of chemical fertilizers. It covers these areas:

- Types and characteristics of chemical fertilizers.
- Understanding fertilizer labels.
- Fertilizers and their effect on soil pH.
- Timing and placement guidelines.
- Avoiding fertilizer burn.
- Fertilizer rate guidelines.
- Troubleshooting faulty fertilizer practices.
- Fertilizer as one part of integrated crop management.
- Extension guidelines for using chemical fertilizers.
- Fertilizer math skills.

What are chemical fertilizers?

As opposed to organic fertilizers which originate from plants and animals (compost, manure, etc.) or are unprocessed minerals like raw rock phosphate, chemical fertilizers are derived from a chemical manufacturing or synthesizing process. Some examples are urea fertilizer (45-46 percent N) made from carbon dioxide and ammonia, or single superphosphate 18-21 percent P₂O₅) made from combining rock phosphate and sulfuric acid.

Are chemical fertilizers appropriate for limited-resource farmers?

We dealt with this issue in detail at the start of Chapter 8 where the overall advantages of organic fertilizers were stressed. It was recommended that farmers be urged to maximize the practical usage of organics wherever feasible. On the other hand, it was also pointed out that many farmers may not have enough available to cover all their crop land. In such cases, chemical fertilizers are often very cost-effective if capital or credit is available. It's not unusual to receive a return of \$3\$10 for every \$1 spent on chemical fertilizers, especially when they're used along with other complementary management practices. However, chemical fertilizers require more skill to use than organics in terms of rate determinations, dosage calculation, timing, and placement.

An introduction to chemical fertilizers

Nutrient content

Chemical fertilizers contain one or more of the "Big 3" (N, P, and K) along with varying amounts of calcium and sulfur. Ordinarily, chemical fertilizers contain no magnesium or micronutrients unless these have been specially added. (Micronutrients are usually applied as separate fertilizers when needed).

The myth of "complete" fertilizer: Those fertilizers like ammonium sulfate (21% N) that contain only one of the Big 3 are called straight fertilizers. Others, like di-ammonium phosphate (18-46-0), contain two of the Big 3. Those such as 12-24-12 which contain N, P, and K are often called complete fertilizers, but this is misleading, because few of them contain all 12 plant mineral nutrients. However, some types may contain significant amounts of some secondary and micronutrients; check the label.

Some NP and NPK fertilizers are simple mechanical mixes of two or more fertilizers. Others are actual chemical combinations with every individual granule having the same nutrient content.

Color as a likely nutrient indicator: The color of a fertilizer's granules is often a useful indicator of its general composition. Grey granules usually indicate an NP, NPK, or straight P fertilizer. White granules usually indicate a straight N fertilizer like urea, ammonium nitrate, or ammonium sulfate. However, potassium sulfate (0-0-50) and most forms of potassium chloride (0-0-60) are also white; some forms of potassium chloride are reddish due to impurities.

Physical forms

- Most come as granules meant for soil application. Some granular fertilizers like ammonium nitrate and urea will also readily dissolve in water and can be sprayed on plant foliage in very dilute form or watered into the soil.
- Liquid formulations are available in some areas. Some can be used for soil application like granules. Others often contain NPK plus micronutrients and are meant for spray applications to the leaves (foliar applications); they are usually rather costly in relation to their nutrient content.
- Soluble powders containing NPK and/or micronutrients may also be available in your area and are meant for foliar application.

How to read a fertilizer label

All reputable commercial chemical fertilizers carry a label giving their nutrient content, specifying not only the NPK content, but also the amounts of secondary nutrients and micronutrients.

The 3-Number Labelling System

With a few exceptions (notably those fertilizers that originate in South Africa), most countries use a universal 3-number labelling system that indicates the N, P, and K content in that order, usually in terms of N, P₂O₅, and K₂O. The numbers refer to percent. For example, a 12-24-12 fertilizer contains 12% N, 24% P₂O₅, and 12% K₂O; 200 kg of 12-24-12 contains 24 kg of N, 48 kg of P₂O₅, and 24 kg of K₂O. A 0-21-0 fertilizer contains 21% P₂O₅ but no N or K.

N-P₂O₅-K₂O vs. N-P-K

The N-P₂O₅-K₂O labelling system is traditional and dates back to the 19th Century when chemical fertilizers were first developed. The P and K contents were analyzed by burning (oxidizing) the fertilizer and then measuring the resulting P₂O₅ (called phosphoric acid or phosphorus pentoxide) and K₂O (potash, potassium oxide) that formed. The N-P₂O₅-K₂O system is known as the oxide form of labelling.

In recent years, a few countries have switched over to the elemental form (straight N, P, and K) for labelling and giving nutrient rates; in some cases, the label will give the fertilizer formula in both the oxide and the elemental forms. Note that N content is given in terms of actual N in both systems.

Don't be confused by this. It really makes little difference whether a fertilizer's NPK content is expressed in the oxide or elemental form as long as the fertilizer labels and the nutrient rate recommendations given by the extension service both use the same form. A fertilizer's true nutrient content is the same whether measured in the oxide or the elemental form, just as the distance between your village and the country's capital is the same whether measured in kilometers or miles. Likewise, the sodium content of a pickle is the same whether measured as pure sodium or sodium chloride.

NOTE: Throughout this manual we'll use the N-P₂O₅-K₂O system since it's still the most common. The terms "P" and "K" will often be used as a short form for phosphorus and potassium with no regard to either labelling system.

When the difference does matter: In some countries like the U.S., both systems are being used. In this case, you'll want to double check and be sure whether the amount of phosphorus or potassium listed on a label or given as a fertilizer recommendation is in the oxide or the elemental form. This affects the actual amount of fertilizer needed, especially in the case of phosphorus. Here's how to convert between the two systems:

$$P \times 2.3 = P_{2}O_{5} \quad P_{2}O_{5} \times 0.44 = P$$

$$K \times 1.2 = K_{2}O \quad K_{2}O \times 0.83 = K$$

Here are 2 practice problems to clear up any confusion:

PROBLEM 1: Suppose soil test results recommend that Suheyla apply phosphorus at the rate of 30 kg of actual P (elemental P) per hectare. If the phosphorus content of the fertilizer is expressed in the oxide form (P₂O₅), how much P₂O₅ will be needed to supply 30 kg elemental P?

SOLUTION:

Since $P_2O_5 = P \times 2.3$, you'd multiply the 30 kg actual P by 2.3 to convert it to P₂O₅. The answer is 69 kg P₂O₅.

PROBLEM 2: Suppose your country uses the elemental system in labelling fertilizers. You see a fertilizer with the formula 15-6.6-12.5 (N-P-K basis). What would the formula be in terms of NP₂O₅-K₂O?

SOLUTION: $6.6\% P \times 2.3 = 15\% P_2O_5$
 $12.5\% K \times 1.2 = 15\% K_2O$

Therefore: 15-6.6-12.5 N-P-K formula equals 15-15-15 on an N-P₂O₅-K₂O basis.

Why Don't the 3 Numbers Add Up to 100?

If you'll look at the fertilizer composition table in Appendix D, you'll notice that the percentages of N, P₂O₅, and K₂O don't even come close to totalling 100. The main reason is that N, P, and K have to be combined with carriers like sulfur, calcium, oxygen, and hydrogen to become stable and usable.

EXAMPLES: Ammonium nitrate fertilizer (33-0-0) has the chemical formula NH₄NO₃. It contains 33% N with the rest being hydrogen and oxygen.

Single superphosphate (0-21-0) has the formula Ca(H₂PO₄)₂CaSO₄. In addition to containing 21% phosphorus P₂O₅ basis), it has calcium, hydrogen, sulfur, and oxygen.

Another reason why the 3 numbers don't total 100 is that some fertilizers have fillers like sand added so that they end up with a whole-number formula. In addition, conditioning agents are sometimes added to improve handling qualities.

Another useful term: Fertilizer ratio

The fertilizer ratio is the ratio between the 3 numbers in a fertilizer's formula and tells the relative proportions of N, P₂O₅ and K₂O (or N, P, K if the elemental system is used) in the fertilizer. Some examples:

Fertilizer Formula Fertilizer Ratio

10-20-10 1:2:1

12-24-12 1:2:1

6-12-6 1:2:1

15-15-15 1:1:1

10-10-10 1:1:1

10-30-10 1:3:1

Understanding fertilizer ratios is very useful when trying to match the kind of fertilizer to a recommendation. For instance, if soil test results recommend applying 30 kg N, 60 kg P₂O₅, and 30 kg K₂O per hectare at planting time, this is a ratio of 1:2:1. It follows that any fertilizer with a

1:2:1 ratio could be used to supply the 3 nutrients in the right proportion and amount (i.e. 300 kg/ha of 10-20-10 or 250 kg/ha of 12-24-12).

Common chemical fertilizers and their characteristics

NOTE: Appendix D lists the nutrient content of common chemical fertilizers.

NITROGEN FERTILIZERS

Nearly all chemical N fertilizers contain either ammonium (NH_4^+) or nitrate (NO_3^-) nitrogen. The nitrate form is quicker acting because it's more immediately mobile (leachable) and reaches the roots sooner if applied to a growing crop. But, remember that ammonium is rather quickly converted to mobile nitrate in warm soils (all of it within 7-10 days).

N fertilizers and soil pH: Most N fertilizers containing ammonium N have a gradual acidifying effect on the soil; this will be covered in detail farther along.

Loss of N by volatilization: All ammonium N fertilizers will release ammonia gas when applied to soils with pH's above 7.0. If applied to the soil surface, significant amounts may be lost to the atmosphere. Urea fertilizer releases ammonia at any pH. Losses can be avoided by placing such fertilizers a few centimeters deep.

Common Nitrogen Fertilizers

Ammonium Nitrate (33-34% N)

- Contains half nitrate N and half ammonium N, so is quicker acting than straight ammonium fertilizers.
- Absorbs moisture and becomes slushy in high humidity; keep bags well sealed.
- Can become explosive if mixed with oil. Releases oxygen when exposed to fire which encourages combustion.

Ammonium Nitrate with Lime (26% N)

- Same as above but is coated with dolomitic limestone to neutralize the acid-forming properties of regular ammonium nitrate and to reduce moisture absorption.

Ammonium Sulfate (20-21% N)

- In addition to N, it contains 23% sulfur (or 69% sulfate).
- Good handling and storage properties

Urea (45-46% N)

- The highest-strength solid form of N.
- Its N is initially in the amide form (NH_2) but is converted to ammonium in moist warm soils within 1-2 days (a week or two in cooler soils) and then to nitrate by soil bacteria.
- Unlike ammonium N fertilizers, urea is mobile and leachable until its amide N has been converted to ammonium.
- Regardless of soil pH, some N will be lost to the atmosphere as ammonia gas if urea is left on the soil surface. Losses are highest above a soil pH of 7.0 and can reach 35% when urea is broadcast (spread) over grass pastures. Losses are minimal, however, if rainfall or irrigation occur within a few hours after such surface applications.

- Can “burn” (injure) seeds and seedlings if placed too close due to release of free ammonia.
 - May sometimes contain excessive amounts of biuret (toxic to plants) due to faulty manufacturing. Biuret is most toxic when urea is mixed with water and applied foliarly (sprayed on the leaves).
 - Tends to absorb moisture, but not as much as ammonium nitrate.
 - Can be fed to ruminants like cattle as a protein source; the rumen bacteria convert the N to protein; BUT urea can be toxic at anything but very low levels and must be fed in combination with certain other feeds. Vinegar is the antidote.
- Sodium Nitrate (16% N) (Chilean nitrate)

- Its nitrate N is readily leachable.
- Unlike most ammonium N fertilizers, it has a gradual basic effect on the soil.
- Can easily burn seeds and seedlings because of its very high salt content. (Fertilizer burn is covered farther along)
- Absorbs moisture and can become slushy in high humidity; keep bags well sealed.
- Expensive because of its low nutrient content relative to shipping costs.

Anhydrous Ammonia (82% N)

- Exists as a liquid under pressure and a gas when released into the soil.
- The highest-strength N fertilizer available.
- Must be injected into moist soil about 15 cm deep to avoid ammonia loss.
- Very dangerous; inhalation and facial exposure can cause blindness and fatal lung damage.
- Requires special storage and application equipment.

Aqua Ammonia (21% N)

- Made by dissolving ammonia gas in water. Has strong odor of ammonia. Unlike anhydrous ammonia, it doesn't have to be applied or stored under pressure.
- Should be applied at least 4-5 cm below the soil surface to avoid loss of ammonia.
- Requires special storage and application equipment.
- Releases irritating fumes.

Potassium Nitrate (13-0-44: See under K fertilizers.

Ammonium Phosphate Fertilizers: See under P fertilizers.

Time-Release or Slow-Release N Fertilizers: They're coated with special substances that reduce their solubility and slow down the rate at which soil bacteria convert ammonium to nitrate.

Leaching losses are much lower, but they're usually too expensive to be cost effective for farmers.

PHOSPHORUS FERTILIZERS

The phosphorus in most chemical fertilizers comes from reacting rock phosphate with sulfuric, phosphoric, or nitric acids or with anhydrous ammonia.

Water-soluble vs. Citrate-soluble vs. Insoluble P

A chemical fertilizer's P can exist in several forms which should be listed on the label:

Water-soluble P: This type of P is soluble in water and moves quickly out of the granules into the soil. But, that doesn't mean it will be 100 percent available to plants, because it's still subject to the soil's ability to tie up (fix) P. When P fertilizer is placed in a band, hole, or half-circle near the row, it's recommended that at least half the fertilizer's P be water-soluble. When P fertilizer is broadcast on soils below pH 7.0, water solubility isn't important, because soil acidity helps dissolve the P.

Citrate-soluble P: This type of P isn't soluble in water but will dissolve in a weak acid solution. Heat-treated rock phosphate contains largely citrate-soluble P which is usable only in acidic soils.

Insoluble P: This type of P isn't soluble in water or a weak acid solution, so it has very limited availability to plants. Most of the P in raw rock phosphate is insoluble and only very slowly available, even in acid soils.

Common Phosphorus Fertilizers

Single Superphosphate (16-22% P₂O₅, 8-12% S): A common P fertilizer and also a good sulfur source. About 78% of its P is water soluble (see above). Made from rock phosphate and sulfuric acid.

Triple or Concentrated Superphosphate (42-48% P₂O₅): Has much more P than single super but only 1-3% sulfur. About 84% of its P is water soluble. Made from rock phosphate and phosphoric acid.

Ammonium Phosphate Fertilizers

There are 3 classes, all with 100% water-soluble P:

- **Mono-ammonium phosphate (11-48-0, 12-61-0):** Tends to work better than all-ammonium phosphate on alkaline soils. Low in sulfur. Less likely to cause burning than DAP.
- **Di-ammonium phosphate (16-48-0, 18-46-0, 21-53-0):** A good P source but can injure seeds or seedlings due to ammonia release if placed too close.
- **Ammonium Phosphate sulfate (16-20-0, 13-39-0):** Both are also good sources of sulfur (91% S in 16-20-0, 7% S in 13-39-0).

Miscellaneous NP and NPK Fertilizers: 20-20-0, 14-14-14, 12-24-12, etc.

Heat-treated Rock Phosphates: These vary a lot in P content and are made by heat treating rock phosphate which greatly increases its low availability. Its P isn't water-soluble but is citrate-soluble (see above) and will slowly become available in acid soils when broadcast. It may be a cheap P source in areas with phosphate deposits but is only recommended for acid soils or where organic matter is very high. It should be in a finely-ground form and be applied by broadcasting to promote the release of its P through soil reaction. It doesn't become available quickly enough to be used as the sole source of added P for short-term annual crops like maize. Much higher rates are needed than for more available forms. Where mycorrhizae soil fungi are abundant (see Chapter 1), they increase the availability of rock phosphate to plant roots.

Raw rock phosphate: See Chapter 8.

Basic Slag (8-25% P₂O₅) A by-product of steel making. About 60-90% of its P is citrate soluble, so it's best used on acid soils, much like heat-treated rock phosphate. It has a gradual basic effect on soils.

POTASSIUM FERTILIZERS

The most common K fertilizers are:

- Potassium chloride (muriate of potash): Contains about 60%-62% K₂O
- Potassium sulfate: Contains about 48-50% K₂O and 18% S.
- Potassium nitrate (13-0-44).
- NPK fertilizers like 10-20-10, etc.

NOTE: Tobacco, potatoes, and sweet potatoes are sensitive to high amounts of chlorides which affect crop quality. In this case, potassium chloride should be avoided or minimized.

SECONDARY NUTRIENT FERTILIZERS (Calcium, Magnesium, Sulfur)

Calcium and Magnesium

Even acid soils have enough calcium for most crops. Where liming is needed and magnesium is also deficient, dolomitic limestone (a mixture of calcium and magnesium carbonates) should be used. Liming with calcium only can also provoke a Mg deficiency. Gypsum has no effect on soil pH and is often used to supply calcium to crops with high needs, such as peanuts, without raising the pH.

Magnesium sulfate (epsom salts; 9-11% Mg) and potassium magnesium sulfate (11% Mg) are other sources and have no effect on soil pH. The Mg content of fertilizers is often expressed in terms of magnesium oxide (MgO); the conversion is: $\text{Mg} \times 1.66 = \text{MgO}$
 $\text{MgO} \times 0.6 = \text{Mg}$

Sulfur

Some common fertilizers are good S sources like single superphosphate (8-12% S), ammonium sulfate (23-24% S), 16-20-0 (9-15% S), and potassium sulfate (17% S). Usually, the higher the NPK content of the fertilizer, the lower the S content (i.e. triple superphosphate contains only 13% S).

Sulfur deficiencies are on the increase in non-industrial areas, due to the growing use of high-analysis fertilizers with lower S contents. It's usually a good idea to include a sulfur-bearing fertilizer in a fertilizer program, especially on acid, sandy soils. Organic fertilizers are a good source of S. Appendix D lists the S content of chemical fertilizers.

The S content of fertilizers is often expressed in terms of SO₄ (sulfate). The conversion is: $\text{S} \times 3 = \text{SO}_4$

MICRONUTRIENT FERTILIZERS

Some NP and NPK fertilizers may have added amounts of micronutrients (check the label) but usually too little to correct deficiencies. If a meaningful amount of a micronutrient is present, it may be indicated by a fourth number in the fertilizer formula, referring to it.

Separate micronutrient fertilizers like copper sulfate, ferrous sulfate (iron), zinc sulfate, manganese sulfate, and borax can be used for soil or foliage (leaf) application. Remember that soil tie-up of added manganese and iron is often a problem on deficient soils (see Chapter 6).

Micronutrient chelates: Specially synthesized forms of micronutrients called chelates are available and used where soil tie-up problems are serious. A chelate has a special molecular structure that protects the micronutrient from being tied up.

Some fungicides like Maneb (containing manganese) and Zineb (containing zinc) can supply these micronutrients in conjunction with a disease control program.

The effect of fertilizers on soil pH

Fertilizers can be acid, basic, or neutral in their effect on soil pH:

- All ammonium N fertilizers (except ammonium nitrate with lime) have a gradual acid-forming effect. That's because the conversion of ammonium (NH_4) to nitrate (NO_3) releases acid-forming hydrogen ions (H^+). The same applies to urea and most NP and NPK fertilizers. (See Table 9-1.)
- Large applications of manure or compost also have a gradual acid-forming effect.
- Nitrate N fertilizers that have their nitrate combined with a strong base have a slightly basic effect (i.e. calcium nitrate, potassium nitrate, sodium nitrate).
- The straight P or K fertilizers have no effect on soil pH. Examples: potassium chloride, potassium sulfate, and the superphosphates.

The Practical Implications of Acid-Forming Fertilizers

Continued use of acid-forming fertilizers over the years will eventually lower soil pH enough to require liming, unless the soil is very alkaline. The rate that soil pH will fall depends on the kind and amount of fertilizer applied and the buffering capacity (negative charge, C.E.C.) of the soil (see Chapter 6). Since clayey soils or those high in organic matter tend to have more buffering capacity, they're usually more resistant to pH change than sandy soils.

So why use acid-forming fertilizers?: They're usually the most available and economical; on alkaline soils, they can actually be beneficial.

TABLE 9-1.

Relative Acidity of Acid-Forming Fertilizers

Lbs. of pure limestone needed to counteract the acidity produced per: FERTILIZER % Nitrogen 100 kg of fertilizer			
Kg of N			
Ammonium nitrate 33%	60 kg	1.8 kg	
Ammonium sulfate 20-21%	110 kg	5.3 kg	
Ammonium phosphate sulfate 16%	88 kg	5.3 kg	
Urea 45%	84 kg	1.8 kg	
Mono-ammonium phosphate (11-48-0)	11%	58 kg	5.3 kg
Di-ammonium phosphate (18-46-0)	18%	63 kg	3.5 kg

NOTE: The far right column of the table is the most meaningful when comparing fertilizers. It shows that ammonium sulfate, ammonium phosphate sulfate, and mono-ammonium phosphate have nearly 3 times the acidifying effect of urea and ammonium nitrate.

Why not add lime to acid-forming fertilizers?: Some fertilizer labels state the amount of lime required to neutralize the acidity produced per 100 kg of the fertilizer, but this is just a legal requirement. Mixing in lime with such a fertilizer will convert much of its ammonium into ammonia gas which is then lost to the air. Don't add lime to the soil after each fertilizer application, either; it's unnecessary and time consuming. At any rate, most limited-resource farmers won't be applying high enough rates to markedly lower the pH in a year or two.

Fertilizer salt index and “burn” potential

As with manure, some chemical fertilizers can injure or even kill seeds or plants when placed too close, and this is called fertilizer “burn”. The likelihood of burn depends on the fertilizer used, its rate and placement, and the type of crop.

What Causes Fertilizer Burn?

Fertilizers are composed of various types of salts such as chlorides, sulfates, and nitrates. Some of these dissolve very readily in the soil water after application. If too high a salt concentration accumulates near the seed or roots, they become unable to absorb enough moisture and show many of the symptoms of drought. If you've taken a biology course, you may remember the principle of osmosis, which seeks to equalize the salt concentration of 2 solutions separated by a permeable membrane (in this case, the seed coat or root hair surface). This is what causes most fertilizer burn. The difference in salt concentration between the inside of the seed or roots and the soil water outside them creates an osmotic “pull” that either prevents water from being taken in or actually draws it out of the plant tissues.

How to Spot Fertilizer Burn

Here are some symptoms that can indicate fertilizer burn.

- Poor seed germination (poor seedling emergence): However, this can be caused by many other factors like low-viability seed, disease, lack of soil moisture, etc.
- Seedlings begin to wilt, and then become yellow and eventually brown and dead, starting at the leaf tips. This can also be caused by other factors such as drought, insects, and diseases. Even established plants can suffer fertilizer burn if a nitrogen sidedressing is applied too close or at too high a rate.

Other Types of Fertilizer Burn

- Some fertilizers like urea and all-ammonium phosphate can also cause burning by releasing free ammonia gas if placed too near seeds, seedlings, or established plants.
- Fertilizer granules containing N and K will cause burn spots on plant leaves if spilled on them.
- Foliar applications will burn the leaves if too strong.

Fertilizers Vary in their Burn Potential

Fertilizers vary in their soluble salt contents. Those containing N and K have the highest salt ratings and are much more likely to cause burn than straight P fertilizers like superphosphate. Some fertilizers like urea and all-ammonium phosphate release free ammonia gas which can also cause burn when placed too close.

TABLE 9-2.

Relative Burn Potential of Common Fertilizers

Fertilizer Formula Salt Index per kg of N-P-K

Sodium nitrate 16-0-0 6.0 GREATEST

Potassium nitrate 14-0-46 5.3 –

Ammonium sulfate 21-0-0 3.2

Ammonium nitrate 33-0-0 2.9

Mono-ammonium phosphate 11-48-0 2.5

Potassium may. Sulfate 0-0-22 2.0 –

Potassium chloride 0-0-60 1.9
Urea* 45-0-0 1.6
Di-ammonium phosphate* 18-46-0 1.6
Potassium sulfate 0-0-50 0.9
Single superphosphate 0-20-0 0.4
Triple superphosphate 0-48-0 0.2 →
Gypsum no NPK 0.25 LEAST

*Urea and DAP may cause more injury than ammonium sulfate due to the release of free ammonia.

How to Prevent Fertilizer Burn

- As shown by Table 9-2, those fertilizers containing N and K are much more likely to cause burn than those that contain only P, such as superphosphate.
- Fertilizer burn is more likely when a localized placement method is used (band, hole, half circle). Follow the distance guidelines carefully that are given in the fertilizer application methods section farther along.
- Fertilizer burn is more likely to occur on sandy soils, since salts and free ammonia move more readily.
- Fertilizer burn is more likely under low-moisture conditions.
- Avoid placing fertilizer in contact with seeds or directly under the seed furrow, even if separated by a few centimeters of soil. Salts can move upward as the soil dries out and can reach the seeds. However, superphosphate can be banded directly under the seed furrow if separated by soil.
- If sidedressing plants by broadcasting an N fertilizer, avoid applying it when the leaves are wet or else the granules may cling to the leaves and cause burn spots.
- If applying an N sidedressing by hand-watering plants with N fertilizer dissolved in water, be sure to wash off the leaves afterwards with plain water.

How to Treat Fertilizer Burn: If water is available, use liberal amounts to flush away the salts from the needs or seedlings. If not, hope for rain!

Basic application principles for N, P, and K

Before covering the specific application methods for chemical fertilizers, let's go over some important principles that affects how N, P, and K can be best applied.

NITROGEN APPLICATION PRINCIPLES

Remember that nearly all chemical fertilizer N is mobile and leachable in the soil, because ammonium N is rapidly converted to mobile nitrate in warm soils. The sandier the soil and the higher the rainfall, the greater the potential leaching losses.

How to Combat Leaching Losses of N

If all the N is applied at planting or transplanting, much may be lost by leaching, especially since young plants have relatively small N needs. For annual crops, such as maize, tomatoes, and cabbage, it's far better to "spoonfeed" the N by applying only 1/3-1/2 of the total (but no less than 30 kg/ha actual N) at planting or transplanting, usually as part of an NP or NPK fertilizer. The remaining 1/2-2/3 is applied in one to several sidedressings along the crop row, starting about 4

weeks after the initial NPK application. Sidedressings usually consist of a straight N fertilizer like urea or ammonium sulfate.

Guidelines for Sidedressing N

The number of sidedressings over which the remaining N is divided depends on 2 factors:

- The potential for leaching losses as influenced by texture and rainfall.
- The length of growing period for the crop.

Here are some examples:

Maize: Usually needs one sidedressing around knee-high stage (about 4 weeks after planting in warm areas). Under high rainfall, especially on sandy soils, 2 sidedressings are recommended: one at knee high, one at tasseling.

Vegetables: A very short season crop like radishes doesn't need a sidedressing. Leafy vegetables such as lettuce, pak choy, and amaranth may get one to several sidedressings (at 3-4 week intervals), depending on whether the whole plant is harvested at once or picked a few leaves at a time over a longer period. Short-term cucurbits like summer squash and cucumber can use 1-2 sidedressings, while longer-tare ones like melons and winter squash might need 2-3. Tomatoes will need from 2 to as many as 6 or more, depending on leaching conditions and length of production. A good interval between sidedressings is 3-4 weeks.

Where to Place Sidedressed N: We'll cover this under application methods in a few pages.

How Deep to Place N: Since N is so mobile, it doesn't have to be placed deep in order to reach the roots, but just enough (2-5 cm deep) to avoid being washed away by rain or losing N as ammonia gas (refer to the section on N fertilizers).

PHOSPHORUS APPLICATION PRINCIPLES

The yield response obtained from applying fertilizer P to P-deficient soils depends a lot on how and when it's applied. Learn these important guidelines:

- Apply P early: Young seedlings need a high concentration of P in their tissues for early growth and root development. One study showed that young maize seedlings take up 22 times more P per unit of length than plants 11 weeks old. P should be applied at planting or transplanting time.
- Remember that applying P in combination with N (if needed) helps stimulate P uptake.
- Application method has a big influence on the soil's ability to tie up applied P. Broadcasting (spreading) fertilizer P usually results in far more tie-up than using a localized placement method (band, hole, or half circle) since it maximizes the contact of each fertilizer granule with soil particles than can cause tie-up. These methods will be explained in the upcoming section on fertilizer application
- Place broadcast P deep: It should be thoroughly mixed into the topsoil with a plow or hoe, except when spread around tree crops (this will be explained farther along under application methods).
- Don't "spoonfeed" P: Depending on application method, the mobility of P varies from nothing to very moderate. Leaching is never a problem, so all of the P can be applied in one application. There's no advantage to making sidedressings as growth proceeds unless P hunger signs develop.

POTASSIUM APPLICATION PRINCIPLES

K ranks midway between N and P in terms of mobility and leaching. As with P, all the K can usually be applied at planting or transplanting as part of an NPK fertilizer or as a straight K fertilizer. Where leaching losses are likely to be high, split applications of K may be needed. Split applications are also recommended for pastures to avoid “luxury consumption” of K. (Refer the section on potassium in Chapter 6.)

Fertilizer application methods explained and compared

The section gives “how to” instructions on the following fertilizer application methods and compares their use:

- Broadcasting
- Localized placement (band, hole, half circle)
- Special placement considerations for furrow irrigated soils.
- Application through the irrigation water
- Foliar applications

Broadcasting

Broadcasting refers to spreading the fertilizer evenly over the soil surface with or without working it into the soil. Localized placement refers to applying fertilizer in a band, hole, or half-circle near the seed row or plants.

NOTE: For convenience, this manual will often refer to these 2 methods by their initials, “BC” and “LP”.

Advantages of Broadcasting

- It gives a more even distribution of nutrients throughout the root zone than the LP method, allowing more roots to come in contact with the fertilizer. It's usually the best method for obtaining maximum yields.
- There's less danger of fertilizer “burn” since the fertilizer is more diluted.
- It may give better distribution of labor by allowing the initial NPK application to be done before planting.

Disadvantages of Broadcasting

- It maximizes the tie-up of fertilizer P: Broadcasting requires from 3-10 times more P to produce the same yield increase compared to using an LP method.
- Although broadcasting may produce higher yields if enough extra P is applied to make up for increased tie-up, it's doubtful whether limited-resource farmers should be aiming for maximum yields. Most of them face several yield-limiting factors ranging from marginal land to insufficient capital.
- It also promotes more K tie-up than the LP method on soils where this is a problem (i.e. those high in 2:1 temperate-type clays such as illite; see Chapter 2).
- It feeds the weeds as well as the crop.
- It's difficult to spread fertilizer evenly by hand.
- Any fertilizer containing P needs to be worked well into the topsoil when broadcast (see below). Not all farmers have the time, labor, or equipment to do this.

- It's not well suited to crops with less extensive root systems (e.g. carrots, lettuce, and potatoes) unless they're spaced very close together. (See the section on intensive gardening in Chapter 4.)

Why Broadcasting P is Usually not a Good Idea

With a few exceptions, chemical fertilizers containing P should not be broadcast over the soil, even if they are plowed or hoed into the topsoil. Broadcasting spreads out the fertilizer too thinly, exposing each granule to full soil contact, which maximizes the opportunity for P fixation (P tie-up). (Review the section on P tie-up in Chapter 6 if this concept isn't clear). Remember that some soils high in tropical-type clays have especially high P fixation capacities. It takes about 3-10 times (or even more) P to provide the same yield boost when broadcast compared to when locally placed.

The "LP" method greatly reduces the opportunity for P tie-up by minimizing the soil's contact with the fertilizer. It also results in a high enough concentration of P to overcome the tie-up ability of the soil immediately surrounding the fertilizer.

Should P Ever be Broadcast?

Farmers with adequate capital and whose soil has only a moderate P tie-up capacity will sometimes make large broadcast applications of P to build up the soil's P status. Such applications may be effective for several years and are often combined with localized placement of smaller amounts near the seed row at planting or transplanting to stimulate early growth. Few limited-resource farmers will be able to afford such large broadcast applications which are better suited to very high yield goals, good capital availability, and soils low in P fixation ability.

However, there are several situations where broadcasting a P fertilizer may be appropriate, even for limited-resource farmers:

- Nursery seedbeds: Given the dense spacings used in beds for producing transplants, the "LP" method isn't practical. Also, nursery seedbeds are very small, so enough extra P can be applied without excessive cost.
- Other small plots where the extra high rates needed can be applied at a reasonable cost, especially those where the seeds have been broadcast, making an LP method difficult. The main rationale for broadcasting would be to avoid the labor of banding fertilizer on direct-planted vegies; where transplants are being set, broadcasting has much less justification, because the plants are set far enough apart to be quickly fertilized by an LP method like a half circle or a hole.
- Flooded rice fields: While flooded, a soil's P tie-up capacity is considerably reduced, so fertilizer P can be broadcast and still have good availability in rice paddies.
- Tree crops: Broadcasting P fertilizer in a broad band (30-40 cm wide) around a tree is an effective application method. It doesn't result in as much P tie-up, since the fertilizer is still fairly concentrated compared to uniformly broadcasting it over the whole field.
- Pastures: Topdressing (broadcasting fertilizer and leaving it on the surface) is the only practical method for applying fertilizer to an established pasture. Even though the P isn't worked into the soil, it's still utilized, since grass roots grow very close to the surface. There's also less P tie-up near the surface due to the high humus level promoted by the pasture.

Broadcast P Must be Worked into the Soil

Broadcast P is virtually immobile due to P tie-up in the soil. It won't reach the roots unless it's thoroughly worked into the topsoil with a hoe or plow. A rake or a disk harrow won't move it down deep enough. Leaving P fertilizer on the soil surface is a common mistake and results in much

less yield response. On soils that have been heavily mulched with rice straw, etc., root development can be quite good near the soil surface (it doesn't dry out as much), and surface broadcasting may be feasible where moisture is adequate to keep the surface continually wet.

AN EXCEPTION: When applying fertilizer P in a wide band around established tree crops, it should be worked in shallowly (2-3 cm) to avoid pruning tree roots which grow close to the surface.

How to Broadcast Fertilizer Evenly

When broadcasting fertilizer by hand, a more even distribution can be obtained by first dividing the dosage into 2-3 parts. Apply the first part while walking lengthwise down the field or plot; apply the 2nd part while walking at right angles to the first pass, and so on.

Hand-cranked fertilizer broadcasters are Also available in some areas, as are tractor drawn spreaders.

Localized placement methods: Band, hole, half-circle

The "LP" methods are usually the best ones for limited-resource farmers whose capital, management, and level of other limiting factors point toward using low to moderate rates of chemical fertilizers (when organics are lacking). As you'll see below, the pros outweigh the cons:

Advantages of the LP Method

- Low to moderate rates of fertilizer (especially P) are more efficiently used than if broadcast. This provides the maximum return per dollar spent, something small farmers should usually be aiming for.
- It minimizes the tie-up of P (and also of K in the less common case where this is a problem).
- It provides an early growth stimulation, especially in cooler soils where plants have trouble taking up enough P. This doesn't always lead to higher yields but helps the crop compete with weeds.
- It doesn't feed the weeds as much.
- It's especially good for crops with less extensive root systems like potatoes, onions, lettuce, and cabbage.

Disadvantages of the LP Method

- It's difficult to produce maximum yields with the LP method alone on low fertility soils. But, maximum yields aren't likely to be the best strategy for most small farmers, anyway, as already mentioned.
- It can be more laborious and time-consuming than the BC method; however, working broadcast fertilizer into the soil may require equal or greater labor.

Depth isn't as Important with "LP" Placed P

Although broadcast P is immobile and needs to be worked well into the topsoil to reach the roots, LP-applied P doesn't always have to be placed as deep. Recent research has shown that fertilizer P will move down to the roots when an LP method is used. That's because there's sufficient concentration of P in the band, hole, or half-circle to overcome the surrounding soil's tie-up ability enough for some downward movement to occur. LP-placed P will reach the roots, even if applied near the soil surface, as long as there's enough rainfall or watering for good plant growth and for moving the P down to the roots.

DISTANCE AND DEPTH GUIDELINES FOR LP APPLICATIONS

Here are specific guidelines for the 3 LP methods of fertilizer application: BANDING, HALFCIRCLE, and HOLE.

NOTE: Liquid “starter” fertilizer solutions that are applied around a transplant when it's set in the ground are also a type of LP method and are covered in Chapter 10 under vegetables.

BANDING

Banding refers to placing the fertilizer in a continuous narrow strip running parallel to the crop row and fairly close to it. Of the 3 LP methods, banding is the best suited for closely-sown row crops like spinach, lettuce, turnips, and drill-planted (one seed per hole) maize. It can also be used on crops with wider in-row spacings, but the half-circle and hole methods may be more convenient. Studies have shown that only one band along the row is needed rather than 2 (one on each side).

NOTE: The banding guidelines below apply to at-planting applications of N, P, and K. Sidedressing N on growing crops will be covered farther on.

Distance from the Seed Row for Band Applications

- When banding fertilizer at planting time, the band should be placed about 5-7.5 cm (3-4 fingers-width) out from the seed furrow. Closer placement may cause burning. More distant placement may prevent the roots from reaching the fertilizer early enough.
- Don't place a fertilizer containing N or K directly under the seeds, even if separated by a few centimeters of soil. Salts from the N and K compounds will move upwards as the soil dries out between waterings or rains and will injure the seeds or young roots.
- With maize, which has fairly good resistance to fertilizer burn, it's possible to place the fertilizer and the seed in the same furrow under certain conditions (see Chapter 10 under maize). With other crops, it's possible to make a single furrow that's wide enough to accommodate a separate fertilize band and seed row.

How Deep to Make the Band

It can be anywhere from on the surface to 10 cm deep, depending on several factors:

- Where there's enough rainfall or overhead irrigation for good growth, there will be enough water to move the banded N, P, and K down to the roots, even if the band is placed at or near the surface. This is true even for P; although immobile when applied broadcast, LP-applied P is mobile if there's enough water for downward movement.
- If on a slope, the band should be a few centimeters deep to prevent fertilizer loss from water runoff.
- To avoid N loss as ammonia gas, don't leave fertilizers containing the ammonium form of N on the soil surface if the soil pH is above 7.0. Urea (45-0-0) releases ammonia at any soil pH.
- Where rainfall is unreliable and there's no irrigation, try to make the band as deep as 7.5-10 cm (about 4 fingers-width to a palm's width) deep, which will place the fertilizer where soil moisture and root growth are more plentiful.

How to Make a Fertilizer Band

Here are 4 methods:

- By hand: This works well on small vegetable plots if soil is soft. Use your fingertips.
- By hoe: Use the hoe blade on edge to make a “V”-shaped furrow.
- An animal-drawn wooden plow or cultivator tine can be used to make a furrow.
- Fertilizer band applicators: Hand-pushed, animal-drawn and tractor-drawn models are available. Some animal-drawn planters and most tractor-drawn planters have accessory band applicators that can be purchased as an option.

Surface Banding: A New Technique

Farmers in the U.S. have recently been trying a new method called surface banding with some success. It's based on the fact that P will move downward to reach the roots when an LP method is used (given that there's enough moisture to move the P downward). As explained below, surface banding is mainly suited to field crops (maize, sorghum, beans, etc.) and can save considerable labor compared with normal banding. Here are the main features of surface banding:

- An NP, NPK, or P fertilizer (depending on soil needs) is applied in bands 50-75 cm apart before or after tillage. The bands run the same way as the future rows will. There's no need to purposely align the plant rows near the bands, because most field crops have extensive root systems. It's also possible to make the bands soon after plant emergence, instead.
- Even if the bands are applied before plowing or hoeing, the fertilizer still ends up being mixed with only 10-15% as much soil as would occur with broadcasting. Therefore, surface banding results in much less P tie-up; however, it's less effective in this respect than normal banding if the surface band is spread out by tillage.

There are several situations where surface banding may not be advisable:

- Sloping land, raised beds, or ridges: Surface-applied fertilizer may be lost by runoff from rainfall or overhead watering unless the bands are worked into the soil.
- Furrow irrigation: Surface banding requires overhead moisture (rainfall, sprinklers, or hand-watering) to move the P downward. Furrow irrigation won't allow surface-applied fertilizer to move downward.

HALF-CIRCLE METHOD

This consists of applying the fertilizer in a semi-circle around the plant, seed, or seed group. It's the best of the 3 LP methods for transplants like tomatoes, pepper, eggplant, and cabbage because of their wider in-row spacings. It also works well with “hill”-planted (cluster-planted) maize and other field crops where spacing between plant groups is wide. A half circle is as effective as a full circle.

Distance from the seeds or plants: For seeds, young seedlings, and newly-set transplants, place the half circle about 10 cm (a palm's width) out.

Depth: Follow the same guidelines as given for banding.

HOLE METHOD

This method consists of placing the fertilizer in a hole near the seed, plant, or plant group. It's likely to be the least effective of the 3 LP methods, because it confines the fertilizer to a very small area, making it available to fewer roots. However, it's still much better than using no fertilizer at all on a poor soil. It's best suited to “hill” planted field crops on large areas, especially where farmers use minimal land preparation and plant with planting sticks. (These can also be used to make the fertilizer hole.). However, where there's enough moisture to move fertilizer downward, it would probably be more effective and quicker to use surface bands or surface half circles if slope isn't a problem.

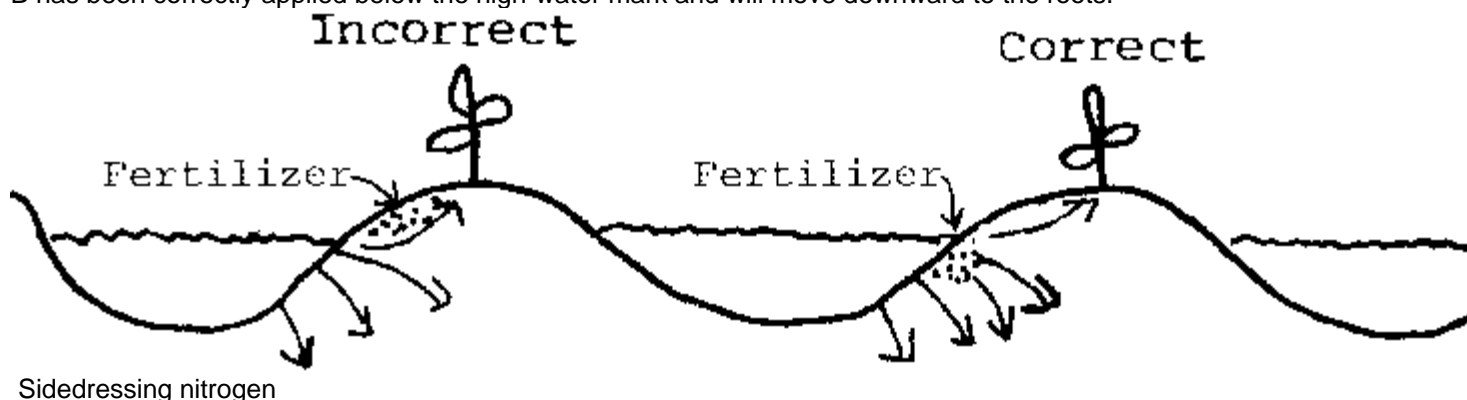
Distance of the hole from the seeds: About 7.5-10 cm (4 fingers-width to a palm's width).

Depth: Where rainfall is unreliable, the hole should ideally be made 10-15 cm deep, but this may not always be practical.

Some special advice for furrow-irrigated soils

When using LP methods on furrow-irrigated soils, make sure that the farmer places the fertilizer below the level that the irrigation water will reach in the furrow (see Figure 911. This places the fertilizer below the "high water mark" and enables mobile nutrients like nitrate N and sulfate to move sideways and downward towards the roots. If placed above the high water line, upward capillary water movement will carry these mobile nutrients to the soil surface where they can't be used. (Upward capillary water movement is the same process that enables kerosene to "climb" up the wick in a lamp.)

FIGURE 9-1: Fertilizer application on furrow-irrigated soils. Fertilizer in row A was placed above the high-water mark and will be carried upward away from the roots. Fertilizer in row B has been correctly applied below the high-water mark and will move downward to the roots.



The reasons for sidedressing N and the number of sidedressings needed were covered a few pages back under N application principles.

Guidelines for Placement of N Sidedressings

There are several ways to sidedress N:

- For close-sown crops, like lettuce and Chinese cabbage, the N fertilizer can be applied in a continuous band parallel to the row and 10-20 cm out from it.
- For vegetables with wider in-row spacings, like tomatoes, eggplant, and cabbage, the half-circle method works well. Place the half circle about 16-20 cm out from the stem. Closer placement may cause injury. Banding can be used instead if more convenient.
- For maize, sorghum, and millet, N can be sidedressed in a band running right down between each row, even if the rows are a meter apart. That's because these cereals have a very extensive root system. By the time these crops are knee high, the roots from adjacent rows have already crossed each other in the row middles.

Depth to sidedress N: If rain or watering will be adequate to move the N downward, the fertilizer only has to be placed deep enough to prevent it being carried away by water runoff or from losing N as ammonia gas. A depth of 2 cm is fine. Much deeper placement may prune roots if the crop is well along.

Combining sidedressing with a weeding: This can be time and labor saving, since the weeding will cover up the N fertilizer the same time.

Mixing fertilizers with water

There are 3 ways of applying fertilizers by mixing them with water:

- Making up a starter solution by dissolving an NP or NPK fertilizer with water. (See the section on vegetables in Chapter 10.)
- Mixing an N fertilizer like urea or ammonium nitrate with water and watering it over plants such as those in a nursery seedbed. (See the section on vegetables in Chapter 10.)

- Soluble forms of NPK fertilizer can be applied through drip-irrigation systems. Research has shown that P applied in this way will move downward to the roots. This is because drip irrigation is essentially an “LP” method of applying water and fertilizer. A typical drip system will concentrate water and fertilizer on 20% or less of the soil surface.
- Where sprinkler irrigation is used, soluble N fertilizers like those above can be injected into the pipeline. This can be wasteful where water application is uneven, however. (To avoid the possibility of fertilizer burn, be sure to irrigate with plain water for a few minutes afterwards.)
- Soluble N sources can also be dissolved in furrow-irrigation water, but this is too wasteful a method.

Foliar fertilizer applications

Micronutrient Applications

Foliar applications are best suited for applying micronutrients. Since very small levels are needed to treat a deficiency, they can be easily applied in one or two applications without causing “burning”. This method is especially well suited to iron and manganese, since it bypasses soil tie-up of these nutrients.

NPK Foliar Applications

Soluble powders or liquids containing NPK may be sold in your area for mixing with water and spraying on crops. Some soluble granular fertilizers like urea can be used for this purpose too. Although sellers of foliar NPK fertilizers often claim very profitable yield increases, here are some facts to consider:

- Numerous trials have shown that NPK foliar applications usually will “green up” the leaves; however, significant yield increases usually don’t occur, as long as enough NPK is being applied to the soil.
- On the other hand, a 1976 trial by CIAT in Colombia obtained a 225 kg/ha yield increase on field beans by spraying them 3 times with a 2.5% solution (by weight) of 11-48-0 (monoammonium phosphate), even though 150 kg/ha of P₂O₅ had been added to the soil. The spray contributed only 10 kg/ha of P₂O₅. However, this soil had a very high P tie-up capacity.
- The soluble powder and liquid foliar fertilizers are much more expensive per unit of nutrient, compared to standard fertilizers.
- Numerous applications may be needed to supply a meaningful amount of NPK through the leaves without burning them.
- Some NPK foliar fertilizers have micronutrients too, but the amounts are usually too small to prevent or cure a deficiency.
- Although foliar applications take effect quickly (1-3 days), they have much less residual value than soil applications.

DETERMINING FERTILIZER RATES

How rates are given

There are 2 basic ways of stating a fertilizer dosage. You’ll probably run into both of these:

1. Kg of actual fertilizer needed per hectare

Example: Apply 300 kg/ha of 10-20-10 to maize at planting, followed by 100 kg/ha of urea (450-0) at knee-high stage.

This type of dosage is very straightforward, since it tells you the kind and amount of actual fertilizer needed. However, you'll still need to calculate how much fertilizer to buy for the field's size and how much to apply per plant or per meter of row length; we'll cover this under fertilizer math farther along.

2. Kg of N, P₂O₅, and K₂O needed per hectare

Example: Soil test results recommend the following fertilizer dosages for a tomato field:

Kg/hectare
N P₂O₅ K₂O
At transplanting 40 80 40
Additional N to apply over 3 sidedressings. 75

This way of stating fertilizer dosages is more complicated since it's up to you and the farmer to determine the amount of fertilizer needed per hectare to satisfy the recommendation. (We'll cover this under fertilizer math) This method is often preferred over #1 above, because the types of fertilizers available may vary a lot from one area to another.

What is the most profitable type and amount of fertilizer for limited-resource farmers?

You may have seen boxes of fertilizer labelled "Tomato Fertilizer" or "Rose Fertilizer" in garden shops; the label may even give dosage rates. Unfortunately, it's not that simple. There's no one type of fertilizer or fertilizer rate that's best for one crop. These depend on several factors:

- Nutrient status of the soil which is best determined by a soil test. (See Chapter 7.)
- Type of crop (legume vs. non-legume, etc.).
- Feasible yield goal as determined by:
 - Limiting soil, weather, moisture, and pest factors
 - Farmer management level
 - Capital available for needed inputs
- Expected cost/return based on costs, likely yield, and estimated price. The latter 2 are especially difficult to project for vegetable crops.

What to Do Where Reliable Recommendations Aren't Available

As you saw in Chapter 7 on evaluating soil fertility, it's not always possible to obtain reliable soil test results or recommendations that are geared to the special circumstances of limited-resource farmers. Nonetheless, you can still develop fairly appropriate recommendations by using this manual and doing some local investigation. Here's how:

- Start by checking at the local extension office to see if reliable results are available for soil tests or fertilizer trials conducted on the same type of soil on nearby farms.
 - Check to make sure that the Ministry of Agriculture hasn't already developed appropriate fertilizer recommendations for the soil involved, based on soil tests or fertilizer trials.
- If such information isn't available, you'll have to start from scratch, beginning with this very useful guideline:

LIMITED-RESOURCE FARMERS SHOULD USUALLY AIM FOR MAXIMUM RETURN PER DOLLAR SPENT. THIS MEANS USING LOW TO MODERATE FERTILIZER RATES BECAUSE OF THE LAW OF DIMINISHING RETURNS.

Fertilizer Response and the Law of Diminishing Returns

Figure 9-2 and Table 9-3 show that the yield response to fertilizer follows the Law of Diminishing returns which has especially important consequences for limited-resource farmers.

FIGURE 9-2: Graph illustrating the Law of Diminishing Returns and its effect on response to fertilizer.

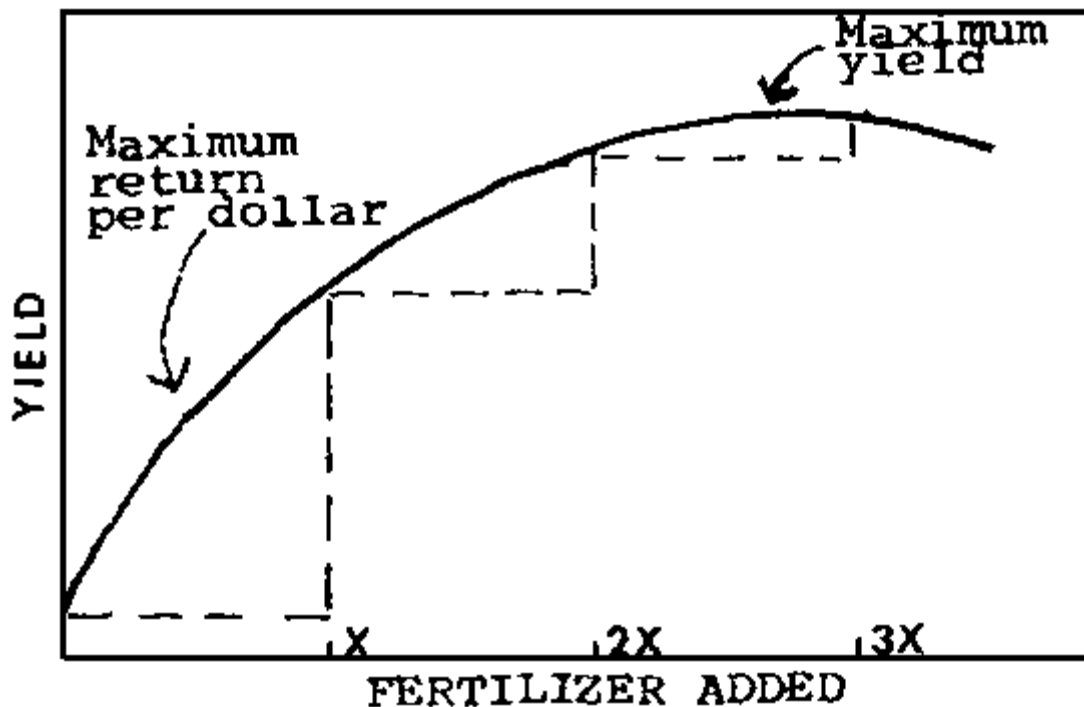


TABLE 9-3.
AN EXAMPLE OF THE LAW OF DIMINISHING RETURNS

Kg of N Applied per Hectare	Maize Yield in Kg per Hectare	Yield Increase in Kg
0	305	-
40	1372	1062
80	2135	763
120	2643	508
160	3024	381
200	3279	255
240	3457	178
280	3584	127
320	3660	76

NOTE: Each soil responds differently. This one was deficient only in N.

- As shown by Fig. 9-2 and Table 9-3, the efficiency of fertilizer response declines as rates increase. This means that a capital-short farmer is usually better off fertilizing a larger area of land at a low to moderate rate than a smaller area at a higher rate. This strategy results in maximum

return per dollar spent on fertilizer.

- Limited-resource farmers don't have enough capital to fertilize all their land to the maximum, which would result in maximum total profit but a much lower return per dollar invested.
- As a farmer's capital situation improves, she can afford to become less efficient in terms of maximum return per dollar and begin to aim more toward maximum total profit by applying more fertilizer per hectare (as long as investment in other appropriate practices isn't sacrificed). This is similar to a large supermarket that makes less return per dollar (due to discount pricing) but makes more total profit than a small grocery because of much higher volume.
- By using low to moderate rates of fertilizer, a limited-resource farmer will be able to fertilize more land and, hopefully, have capital left over to invest in complementary improved practices. To help clarify things, suppose that Table 9-3 applies to a limited-resource farm family with 2 hectares of maize. Let's say they can only afford to buy 80 kg of N and still have enough capital left to invest in other complementary practices. If they applied all 80 kg to one hectare, they would harvest a total of 1672 kg of maize off the 2 hectares (1372 + 305). If they applied 40 kg of N to each hectare, they would harvest 2744 kg of maize, or 1072 kg more than in the first case.

Substitution of fertilizer for land: It can be argued from the above example that it takes more labor to fertilize 2 hectares instead of one. However, the other side is that fertilizer use can reduce the amount of land (and, therefore, labor) needed to produce a given amount of crop, thus cutting costs and allowing for more diversity of production.

SOME GUIDELINES FOR LOW, MEDIUM, AND HIGH NPK RATES

Table 9-4 gives some "ballpark" figures for low, medium, and high NPK rates, based on the realities of limited-resource farming. Even the "high" rates in the table would be considered on the low side by many farmers in North America and Europe who have access to adequate credit. For example, it's not uncommon for U.S. Corn Belt farmers to apply 200 kg of actual N per hectare on maize. Such rates may produce maximum profit per hectare but at the price of a lower return on capital, a less efficient yield response, and possible pollution of ground water and lakes by excess nitrate.

TABLE 9-4

GUIDELINES FOR LOW, MEDIUM, AND HIGH NPK RATES GEARED TO LIMITED-RESOURCE FARMING*

NOTE: DO NOT USE THIS TABLE WITHOUT CONSULTING THE QUALIFICATIONS LISTED BELOW IT.

LOW

(kg/hectare)

MEDIUM

(kg/hectare)

HIGH**

(kg/hectare)

N 35-55 60-90 100+

P2O5 25-35 40-60 70+

K2O 30-40 50-70 80+

* Refers to total NPK for one crop; don't include a nursery seedbed application or the use of a starter fertilizer solution in these totals.

** "HIGH" doesn't necessarily imply "too high".

Qualifications to Table 9-4

1. The P rates in the table are based on localized placement, not on broadcasting. About 310

times more P is needed if broadcast.

2. You must consider the soil's likely fertility status. A soil high in available K, would need little or no fertilizer K. Most soils that have been under cropping for a few years are low in N. Most soils are low to medium in P.

3. You must consider the type of crop:

- The N rates in Table 9-4 are geared to high users like maize, sorghum, rice, leafy vegetables, tomatoes, and improved potato varieties. Most root crops have moderate N needs.
- Legumes vs. non-legumes: Peanuts, cowpeas, soybeans, mungbeans, pigeonpeas, chickpeas, and winged beans are very efficient N fixers and seldom require N as long as the proper strain of rhizobia bacteria is present. Beans (*Phaseolus vulgaris*) and garden peas (*Pisum sativum*) are only about half as efficient and can use up to 50-60 kg/ha of N.
- Bananas and starchy root crops like taro, cassava, and potatoes have the highest K needs. Cereals often respond less than legumes to applied K, because they are more efficient K extractors.
- Before using Table 9-4, see if the crop is listed in Chapter 10 where more specific fertilizer guidelines are given.

4. You must also consider limiting factors that may affect the response to fertilizer such as: moisture, pests, diseases, soil problems, weather, farmer management level, etc. These are covered in detail in a section on integrated crop production management farther along in this chapter.

GUIDELINES FOR MAGNESIUM AND MICRONUTRIENT RATES

The following rates are generalized dosages for curing deficiencies when no location-specific recommendations exist. In addition, you can look up the particular crop in Chapter 10 to see if more specific recommendations are given. Crops and even cultivars (varieties) vary in their micronutrient needs.

NOTE: A wetting agent (spreader) should be used when making foliar applications to assure uniform leaf coverage; if a commercial one isn't available, you can use a mild liquid dishwashing detergent at 1-3 cc/liter.

MAGNESIUM: 3035 kg/ha actual magnesium which equals 150175 kg/ha (1518 g/sq. meter) of epsom salts (magnesium sulfate) which contain about 20% pure Mg. For foliar applications, apply 1228 grams per liter of water.

IRON: For soil applications, chelated iron (912% iron) should be used at 2040 kg/ha to avoid soil tie-up. Ferrous sulfate (20% Fe) is very effective for foliar application as a 12% spray (1020 grams ferrous sulfate per liter of water).

MANGANESE: Manganese sulfate can be banded at 510 kg/ha which helps protect it from tie-up (it can be mixed with the NPK fertilizer). Foliar applications of manganese sulfate can be very effective, using a 12% spray (1020 grams manganese sulfate per liter).

COPPER: Copper sulfate pentahydrate (25% Cu) can be broadcast at 2540 kg/ha (2.54 g/sq. meter) on mineral soils and at 100300 kg/ha (1030 g/sq. meter) on peat soils. Foliar applications can be made using copper sulfate pentahydrate at 36 grams/liter.

ZINC: 1040 kg/ha (14 g/sq. meter) of zinc sulfate; band at lower rates, broadcast at higher rates. Foliar applications are very effective using a 12% solution of zinc sulfate (1020 g/liter).

BORON: Borax (11% B) can be broadcast at 1025 kg/ha (1.025 g/sq. meter) for legumes and certain root crops like sweetpotatoes; for other crops, try 510 kg/ha of borax (0.51.0 g/sq. meter). Use the lower rates on sandy soils. Boron can easily injure plants or seeds if applied at too high a rate or concentrated too close to the row.

MOLYBDENUM: Mo deficiency is most common on overly acid soils because of tie-up; liming will often cure a deficiency. Sodium molybdate (40% Mo) can be broadcast at 5001000 grams/hectare. Treating the seed with sodium or ammonium molybdate is the most common way of treating deficiencies (see the section on soybeans in Chapter 10). Excess Mo applied to forage crops can be toxic to livestock.

IMPORTANCE OF ACHIEVING THE RIGHT NUTRIENT BALANCE

If two or more nutrients are deficient simultaneously (very likely), adding only one may give very disappointing results. For example, look at the results of the fertilizer trial below conducted on a soil where both N and P were low:

Treatment Maize Yield Per Hectare Yield Increase

None 240 kg -N

only 720 kg 480 kg

P only 1120 kg 880 kg

N + P 3250 kg 3110 kg

In other cases, an excess of one nutrient relative to another can cause imbalances:

- A high ratio of potassium or ammonium N to magnesium can cause a deficiency of magnesium in susceptible crops such as tobacco and pasture grasses.
 - A high ratio of potassium to calcium may provoke a calcium deficiency in peanuts.
 - Large applications of phosphorus can cause deficiencies of iron or zinc, especially when an LP application method is used. (On the other hand, P fertilizer improves the availability of manganese; this can be important for crops such as oats, soybeans, beans, and peanuts which are especially susceptible to manganese deficiencies.)
 - A high ratio of calcium to magnesium can cause a magnesium deficiency. This is common where acid soils are limed with materials that contain calcium only instead of with dolomitic limestone.
 - Overliming a soil can cause micronutrient deficiencies (except for molybdenum).
 - Excess soluble copper and manganese can cause iron deficiencies and vice-versa.
- Troubleshooting faulty fertilizer practices

You can see now that chemical fertilizers require much more skill to use properly than organic fertilizers in terms of selection, rates, dosage calculations, and application. Now that we've covered most of this, it's easy to understand why the misapplication of chemical fertilizer is a very common problem, whether in the Third World or elsewhere.

Hopefully, this chapter has given you a solid grounding for using chemical fertilizers appropriately. To help tie together all the principles and practices covered, let's practice troubleshooting some common faulty fertilizer recommendations.

What to Look For

When evaluating a fertilizer recommendation, check the following:

- Type of fertilizer
 - Amount of fertilizer
 - Application method: BC vs. LP, depth, distance
 - Timing of applications
 - Proportion of total N applied at planting/transplanting
- RECOMMENDATION 1: 250 kg/ha of 14-14-14 broadcast and left on the soil surface a day before planting Chinese cabbage, followed by 150 kg/ha of ammonium nitrate (33-0-0) a month later in a band 20 cm out from the row and 2 cm deep.

WHAT'S WRONG?: This recommendation applies a total of 85 kg N, 35 kg P₂O₅, and 35 kg K₂O per hectare. The N rate falls in the medium category, and the P and K rates in the low category, which is OK as long as the soil doesn't have a severe P or K deficiency. However, broadcasting such a low rate of P is a serious mistake and will result in most of it being tied up and unavailable to the crop. It should be banded. Remember that the fertilizer rate table (Table 9-4) is based on localized placement of P; from 3-10 times or more may be needed if broadcasting is used. It's also a big mistake to leave the 14-14-14 on the soil surface; broadcast P is immobile and won't reach the roots unless thoroughly worked into the top 15-20 cm with a hoe or plow. The proportion of total N (40%) applied at planting is OK. The N sidedressing is applied correctly and at the right time.

RECOMMENDATION 2: 125 kg/ha of urea (45-0-0) applied when grain sorghum is planted, followed by a sidedressing of 200 kg/ha of 16-20-0 at knee high stage.

WHAT'S WRONG?: It's backwards! NP or NPK fertilizer should always be applied at planting (or transplanting), never as a sidedressing. P needs early application, because young plants need a high concentration in their tissues for good early growth and root development. Besides, applying the urea first puts on far more N (63%) than the 1/3-1/2 that should be applied at planting. What about the NPK dosage? It works out to about 88 kg N, 40 kg P₂O₅, and 40 kg K₂O per hectare which are all in the acceptable range of the rate table a few pages back. However, some extra K might be needed if the soil has a low level.

RECOMMENDATION 3: 300 kg/ha of 12-24-12 when tomatoes are transplanted, applied in a half circle 30 cm out from the stem and 5 cm deep, followed by a sidedressing of 150 kg/ha of ammonium sulfate (21-0-0) every 4 weeks until harvest is over. The sidedressing is applied in a half circle 10 cm out from the stem and 2 cm deep.

WHAT'S WRONG?: To start with, the half-circle for the initial NPK application is placed too far away (30 cm) from the plants. A palm's-width (10 cm) will allow earlier utilization of the fertilizer. The 5 cm depth of the half-circle is correct, as long as there will be sufficient moisture to move the P downward toward the roots.

Secondly, the N sidedressing is placed too close (10 cm) to the stems and may injure the plants; it should be placed about 20-25 cm from the stems.

The N, P, and K dosages seem reasonable, although more K might be needed on a low-K soil. The monthly sidedressings are appropriate, including the rate of 30 kg/ha of actual N per application. In the case of well managed, vine-type (indeterminate) tomatoes, the production period could continue for up to 6 months or more, requiring 6 or more such sidedressings totalling 180 kg/ha or more of actual N. This might seem excessive, but not when you consider the unusually long production period and the potential yield.

RECOMMENDATION 4: 300 kg/ha of 16-20-0 applied when peanuts are planted, followed by a sidedressing of 100 kg/ha of urea (45-0-0) 30 days later.

WHAT'S WRONG?: Peanuts are a very efficient N-fixing legume which can normally satisfy their entire N needs if the proper strain of rhizobia bacteria is present. Even if the soil lacked the right type of rhizobia, it would be much more economical to inoculate the seed with the bacteria than to buy N fertilizer (see the section on peanuts in Chapter 10). Also, K may be needed

RECOMMENDATION 5: Broadcasting 400 kg/ha of 10-10-20 over a nursery seedbed for raising cabbage transplants and working it into the top 5 cm of soil with a rake. (Assume that manure or compost aren't available).

WHAT'S WRONG?: First, a rake will not move broadcast P deep enough into the soil for good availability to the roots. A good hoeing is needed to work the fertilizer into the top 10 cm of soil.

Second, broadcasting is the only feasible method for applying NPK fertilizer to a nursery seedbed (especially if the seed was broadcast), but the rate of P is far too low this. It's not a simple matter of increasing the amount of 10-10-20 either, because you'll end up applying way too much and especially K in order to put on enough P. The real problem is the fertilizer's ratio (1:1:2). In order to apply the high amount of P needed (remember, up to 10 times more is required when the BC method is used) without over-applying N and K, you want a fertilizer with a ratio of around 1:3:1 or

1:4:1. If this isn't available, you can make your own by mixing the 10-10-20 with single superphosphate (0-20-0) or triple superphosphate (0-48-0). This is covered in the fertilizer math section at the end of this chapter.

RECOMMENDATION 6: 100 kg/ha of 16-48-0 applied when maize is planted, followed by a sidedressing of 400 kg/ha of ammonium sulfate (20-0-0) when the tassels and silks emerge.

WHAT'S WRONG?: First, a total of 96 kg/ha of N is being applied in the 2 applications (16 + 80) which is acceptable, as long as moisture is adequate and the crop is well managed. But, remember that 1/3-1/2 of the total N should be applied at planting. In this case, only about 16% of the N was put on at planting, which is too little. As a general rule, at least 30 kg/ha of actual N should be applied at planting, mainly to help avoid temporary tie-up of soil N by the bacteria that are decomposing crop residues. (See Chapter 6 under N.) The problem with 16-48-0 is that its

1:3:0 ratio results in too little N being applied, given the rate needed to supply the 48 kg/ha of P₂O₅ (a satisfactory amount). One solution would be to add some 20-0-0 to the 16-48-0 to supply the extra N needed at planting.

Second, the N sidedressing is applied too late. In warm climates, maize starts tasseling and silking about 50-70 days after planting. Applying the N this late will give much less of a yield boost, because the plants' need for N begins best time for sidedressing. This is usually when maize has reached the knee-high stage.

Third, the P rate is acceptable, but K may be needed.

RECOMMENDATION 7: Making up a starter fertilizer solution by dissolving 4 cc of urea (45-0-0) in a liter of water and pouring 250 cc around the base of each newly set tomato transplant. No other fertilizer, chemical or organic is applied for the rest of growth.

WHAT'S WRONG?: Urea will have little benefit as a starter solution. What's needed is an NP or NPK fertilizer with a good ratio of P which will help stimulate new root growth. A straight P fertilizer could be used, but N helps promote the uptake of P by the roots. Some examples of fertilizers suitable for making up starter solutions are 12-24-12, 10-30-10, 18-46-0, and 16-20-0.

In addition, the starter solution isn't meant to replace the normal NP or NPK fertilizer application nor the sidedressing either. It provides only enough nutrients for the first week or so of growth. (For more information on starter solutions, see the section on vegetables in Chapter 10.)

RECOMMENDATION 8: Applying 10-20-10 to potatoes at planting time by banding it directly under the seed pieces, separated by 3-4 cm of soil. Then applying a sidedressing of urea one month after emergence by sprinkling it on the soil surface along the row.

WHAT'S WRONG?: First, there's danger of burning the seed pieces due to upward movement of fertilizer salts as the soil dries out between rains or waterings. The band should either be applied about 3 fingers-width (7.5 cm) off to the side or separated vertically from the seed pieces by at least 12 cm of soil.

Second, urea releases free ammonia gas which will cause significant N loss unless the urea is worked into the soil a bit. Rainfall or overhead watering could also wash the fertilizer off the ridges or "hills" on which potatoes are usually grown. Applying it right before the plants are hilled up with soil or weeded is a good way to accomplish this without extra work.

Getting the most out of fertilizer use: crop management as an integrated system

It's true that fertilizer use can be the factor producing the largest yield increase, especially on low-fertility soils. However, it's important to realize that low soil fertility is just one of many limiting factors that can affect crop yields. Many a farmer and extension worker have learned the hard way that chemical fertilizer alone may give disappointing results. As a sole input, chemical fertilizers have a further disadvantage in that they provide none of the additional benefits that organic fertilizers offer (i.e. filth improvement, etc.). In this case, it's particularly important to be sure that other limiting factors are addressed, aside from fertility alone.

The "Package" Approach to Yield Improvement

One essential part of successful farm or garden project management is selecting and implementing an integrated system of complementary practices designed to favor production and

control major limiting factors. Trying to overcome several major limiting factors at once usually gives a more impressive yield increase than tackling them one at a time. A well-designed and appropriate “package” of practices will actually lower farmer risk, and the synergistic effect can be remarkable. The results of a farm trial on dryland wheat in Mexico shown below are a good example:

Treatment Yield Increase

Fertilizer only 5%

Irrigation only 135%

Fert. + irrigation 700%

Some Possible Objections to the “Package” Approach

In *Two Ears of Corn*, the widely-respected book on grassroots ag extension, author Roland Bunch points out the possible disadvantages of “package” technologies that involve more than two or three new practices. He favors purposely limiting the technology for several reasons:

- Most of the successful people-centered extension projects are ones that started slowly and on a small scale. Each new practice increases program complexity in terms of research, training (of extensionists and farmers), supervision, and availability of inputs.
- In order for innovations to achieve long-term success, they must be adopted by a significant portion of farmers (roughly 25-45%). This “critical mass” is vital to assure eventual wide-spread adoption. Simple packages create less confusion and allow more people to be reached.
- Simple packages that involve a minimum of purchased inputs are more likely to be affordable to small farmers. High-input packages are income-biased and favor the wealthier farmers.
- Packages that achieve spectacular yield and income increases may promote even more economic disparity in a community and lead to jealousy and resentment. In addition, limited-resource farmers (and most of us, for that matter) may not use such sudden income increases wisely.

It's important to note that a “package” doesn't have to include purchased inputs that involve considerable capital.

When working with limited-resource farmers or gardening projects, there are a number of low- or no-cost practices whose introduction can precede or accompany the use of chemical (or organic) fertilizer such as:

- More timely and thorough weeding
- Better crop and variety selection
- Better water management (See Chapter 5)
- Better plant spacing and thinning
- Erosion control (See Chapter 3)
- Fencing
- Mulching
- Improved recordkeeping

SOME LIMITING FACTORS THAT CAN SERIOUSLY AFFECT FERTILIZER RESPONSE

Available Moisture

Crops can't utilize nearly as much fertilizer when moisture is limiting, although low to moderate rates will help improve water use efficiency. For example, in the semi-arid wheat regions of the U.S., fertilizer nitrogen recommendations are often geared to the amount of stored subsoil moisture and outlook for rain.

Drought-resistant crops like sorghum and millet exhibit much less response to fertilizer when grown under low rainfall conditions, compared to when moisture is sufficient for good yields. In fact, fertilizer may not show a profitable return where moisture is seriously limited.

Another moisture-related instance where fertilizer use is unlikely to be cost-effective is recessionary agriculture. In this system, crops are planted in the saturated soil of riverbanks and floodplains as water levels recede after the rainy season ends. In this case, applied fertilizer will soon end up in dry soil as moisture levels drop, unless it's feasible to hand-water the crop from the river or other source.

Type of Crop

Given adequate moisture and an appropriate variety, cereal grains, most pulses, most vegetables, bananas, sugarcane, and pastures tend to show more response to fertilizer than coffee, cacao, and most tree crops. Soybeans and peanuts often respond better to residual fertility remaining from applications to previous crops.

Variety

Improved varieties, including hybrids, generally give a better response to fertilizer than traditional ones, though this isn't always the case. For example, during the first years of the Puebla Maize Project in Mexico, some of the native varieties consistently outyielded anything the plant breeders developed. In India, on the other hand, an adapted hybrid yielded 4 times as much as the traditional local variety when both were grown under the same package of practices.

Varieties of the same crop can vary greatly in important characteristics aside from fertilizer response such as drought and heat tolerance, resistance to diseases and nematodes. Each of these can also have a big bearing on yield. Be sure that the variety used is well adapted to the area's growing conditions. Be particularly careful with donated seed from U.S. seed companies that is often distributed by relief agencies.

Planting Date: This is an important consideration in areas where delayed, premature, or unseasonal planting increases the likelihood of yield-limiting stresses such as excessive heat or cold, too much or too little moisture, insects, and diseases.

Plant Density (Plant population)

Too low a plant density is a common cause of poor fertilizer response, especially with cereal grains. Where soil fertility is low, farmers tend to plant fewer plants per hectare so that each plant gets a better share of the limited amount of nutrients. Such low plant populations may not be able to respond well to added nutrients. The reason is that the individual plant's yield-determining factors, such as number of ears per plant, ear size, or seeds per head, may reach their limit at relatively low NPK rates. If so, it may be necessary to increase plant population when fertilizer is introduced in order to obtain more grain yield. Caution is needed here, since varieties vary in their population tolerance, and overly-high plant densities may encourage lodging (tipping over) in cereal crops or use up scarce soil moisture in drought-prone areas.

Soil Limiting Factors: Poor filth, poor drainage, soil compaction, low water-holding capacity, and pH problems all have an adverse effect on fertilizer response.

Weed Control: Weeds not only compete with the crop for sunlight, water, and nutrients, but harbor insects and diseases as well.

Insects, Diseases, and Soil Nematodes: While a well-nourished plant has better resistance to most diseases and pests, they can still wipe out profits if not controlled.

Management Level: The farmer's or project's willingness and ability to implement the minimum level of needed management is a crucial factor. This includes general management skills such as

planning and timeliness, as well as essential practices such as weed and insect control where needed.

Understanding fertilizer math

There's a surprising amount of math devolved in using chemical fertilizers. This section covers the following useful fertilizer math skills:

- Converting fertilizer recommendations from an N-P₂O₅-K₂O basis to the actual kind and amount of fertilizer needed.
 - Selecting the most economical fertilizer.
 - Mixing fertilizers.
 - Determining how much fertilizer is needed per area, per Plant, and Per length of row.
 - Converting fertilizer dosages from weight to volume.
- USE THE METRIC SYSTEM!: It greatly simplifies fertilizer math and most other calculations. Even if your country doesn't use metrics, it's well worth your while to use it for calculation purposes. Here's how to quickly convert some common non-metric units into metric (see Appendix A also):

lbs./acre X 1.12 = kg/ha; 1 lb. = 0.454 kg = 454 g

1 acre = about 4000 sq. meters (actually 4048 m²)

1 manzana (Latin America) = 7000 sq. meters

4" = 10 cm

8" = 20 cm

12" = 30 cm

16" = 40 cm,

18" = 45 cm

24" = 60 cm

30" = 75 cm

32" = 80 cm,

36" = 90 cm

40" = 100 cm

Converting recommendations from an N, P₂O₅, K₂O basis to the actual kind and amount of fertilizer needed

As explained in Chapter 9, fertilizer recommendations aren't always given in terms of actual kind and amount of fertilizer. Instead, technical brochures and soil testing labs often give recommendations in terms of the amount of N, P₂O₅, and K₂O needed per hectare. In this case, it's up to you and the farmer to determine what kind and amount of actual fertilizer is needed per hectare to match this recommendation. Let's run through a practice problem:

PROBLEM 1: A farmer's cooperative has just received the following fertilizer recommendation for a one hectare tomato field.

kg/hectare

N P₂O₅ K₂O

At transplanting 40 80 40

1st sidedressing at 30 days 30
2nd sidedressing at 60 days 30
3rd sidedressing at 90 days 30

Suppose the local ag supply store has the following fertilizers available. What kind will be needed, how much of each, and what will the cost be?

Fertilizers Available Cost per 50 kg Sack

15-15-15 \$18
16-20-0 \$15
20-10-5 \$14
10-20-10 \$16
20-0-0 \$12

SOLUTION

STEP 1: Let's begin with the 40-80-40 transplanting recommendation. The first thing to do is to look at the ratio of N:P2O5:K2O and then look for a fertilizer with a similar ratio. The 40-80-40 figure has a ratio of 1:2:1. Look at the fertilizer list and you'll see that 10-20-10 is the only one with a 1:2:1 ratio, so it's the one that's needed.

STEP 2: There are 2 ways to find out how much 10-20-10 is needed to supply the 40 kg N, 80 kg P2O5, and 40 kg K2O needed for the hectare:

- You know that each 100 kg of 10-20-10 supplies 10 kg of N, 20 kg of P2O5, and 10 kg of K2O. Therefore 400 kg would supply 40-80-40.
- The second way is to divide the percentage of N, P2O5 or K2O in the 10-20-10 into the respective amount of N, P2O5, or K2O needed. Let's do this using N:
Note that you would get the same answer using P2O5 or K2O so it's only necessary to do this division once.

STEP 3: Now what about the N sidedressings of 30 kg actual N each? In this case, choosing the right fertilizer is easy, since the 20-0-0 fertilizer is the only one containing just N. To find out how much 20-0-0 will be needed to supply the 30 kg of N needed for a sidedressing, use one of the 2 methods in STEP 2 as follows:

- You know that each 100 kg of 20-0-0 supplies 20 kg of N. 200 kg would supply 40 kg N. It would take 150 kg of 20-0-0 to supply 30 kg (i.e. $150 \times 20\% = 30$)
- Divide 20% into 30 kg which gives you 150 kg.

Therefore, 3 sidedressing of 150 kg 20-0-0 each will be needed for a total of 450 kg.

STEP 4: You've determined that 400 kg of 10-20-10 and 450 kg of 20-0-0 are needed for the hectare, so you can now calculate the cost:

400 kg 10-20-10 at \$16/100 kg = \$64
450 kg 20-0-0 at \$12/100 kg = \$54
\$118 TOTAL

You won't always be able to fit a recommendation exactly, because the right type of fertilizer may not be available locally. At any rate, you don't have to be exact, since soil tests and recommendations aren't 100% accurate anyway. But, do try to get within 10-25% of the amounts recommended. There's nothing wrong with having to apply more P than needed in order to supply enough K or vice-versa; P won't leach, and K is fairly immobile. However, avoid putting too much N on at planting or leaching losses may be high.

Let's look at a situation where the fertilizers don't exactly fit the recommendation (Problem 2):

PROBLEM 2: Soil test results recommend that Fatou fertilize her maize field as follows:

kg per hectare
N P₂O₅ K₂O
At planting 30 50 40
At knee high stage 50

Given the following fertilizers, how much and what kind will be needed per hectare?

Fertilizers Available

12-24-12
13-13-20
14-14-14
18-46-0
33-0-0

SOLUTION

STEP 1: Let's begin with the planting recommendation of 30 kg N, 50 kg P₂O₅, and 40 kg K₂O. That's a 3:5:4 ratio (or 1:1.7:1.3). None of the available fertilizers has this ratio, but 12-24-12 is the closest with a 1:2:1 ratio.

STEP 2: Let's figure out how much 12-24-12 is needed to supply the 30 kg of initial N:

250 kg of 12-24-12 per hectare would supply 30 kg N, 60 kg P₂O₅ and 30 kg K₂O. This falls short on K₂O. by about 25% but runs over on P₂O₅ about 20% This is still satisfactory. Now what would happen if we tried to supply the exact amount of P₂O₅ (50 kg) using 12-24-12?:

208 kg/hectare of 12-24-12 supplies 25-50-25 which is about 20% less N and 40% less K₂O. than called for.

The 3rd option is to see how much 12-24-12 it would take to supply the exact amount of K₂O (40 kg) called for:

333 kg of 12-24-12/hectare supplies 40-80-40 which is about 30% more N and 60% more P₂O₅ than called for at planting. You could adjust for the extra N by applying less in the sidedressing, but there's no way to compensate for the 30 kg extra P₂O₅ applied. True, some of this excess will be available to future crops, but at the expense of having to buy about 33% more 12-24-12 compared to the 250 kg rate.

Thus, of the 3 options, the first one of applying 250 kg of 12-24-12 is best.

STEP 3: Now for the N sidedressing. The 33-0-0 fertilizer (ammonium nitrate) is the only straight N source, so it's the one to use. Calculate the amount needed to supply the 50 kg of N as follows:

Selecting the most economical fertilizer

You can't compare a 14-14-14 and 10-30-10 fertilizer on the basis of cost per unit of nutrient for 2 reasons:

- A 1:1:1 ratio fertilizer may be better suited than a 1:3:1 ratio or vice-versa, depending on the soil and the crop.
 - N, P₂O₅ and K₂O. don't necessarily cost the same per kg of nutrient.
- However, you can compare straight fertilizers having just one of the "Big 3", such as urea (45-0-0) vs. ammonium sulfate (20-0-0), or single superphosphate (0-20-0) vs. triple superphosphate (0-48-0). You can also compare NP or NPK fertilizers having the same ratio, such as 10-20-10 and 12-24-12.

When comparing several sources of the same nutrient as to cost, what counts is the cost per kg of nutrient, not the cost per sack. Let's run through a practice problem:

PROBLEM 3: Which of the 3 N fertilizers below is the most economical source of N, other considerations aside?

Fertilizer % N Cost per 50 kg sack

Urea 45% \$18.00

Ammonium nitrate 33% \$15.84

Ammonium sulfate 21% \$11.76

SOLUTION: Although ammonium sulfate has the lowest cost per sack, it's not necessarily the cheapest. The real test is the cost per kg of N. Here's how to calculate it:

UREA: A 50 kg sack contains 22.5 kg of N (50 kg x 45%)

\$18.00/22.5 kg N = \$0.80 per kg of N

AMMONIUM NITRATE: A 50 kg sack contains 16.5 kg of N.

\$15.84/16.5 kg N = \$0.96/kg of N

AMMONIUM SULFATE: A 50 kg sack contains 10.5 kg of N.

\$11.76/10.5 kg N = \$1.12/kg of N

This makes urea the cheapest source of N. Usually, the fertilizer with the highest content of the nutrient will be the most economical due to lower shipping costs per unit of actual nutrient. However, this isn't always the case.

Other factors may be important aside from the cost per kg of nutrient. Although it's the most economical (in this case), urea is a very highly concentrated source of N; farmers unfamiliar with urea may over-apply it and waste money or injure their crops. As for ammonium sulfate, it's often the most costly per kg of N, yet it might be the best choice for a sulfur-deficient soil, unless another sulfur-bearing fertilizer were used at planting time. On the other hand, ammonium sulfate is considerably more acid forming in its long-term effect on soil pH than either urea or ammonium nitrate (see Table 9-1). Ammonium nitrate is a quicker-acting N source than ammonium sulfate or urea, because half of its N is already in the mobile, nitrate form. It might be the best choice where a crop is showing N deficiency symptoms (see Appendix E) or where sidedressing has been delayed.

Mixing different fertilizers

There are cases where it's necessary to mix 2 or 3 different fertilizers together in order to obtain the nutrient ratio needed to suit a recommendation. For example:

PROBLEM 4: Suppose that the extension office recommends the following fertilizer rates for cabbage at planting time:

kg per hectare
N P₂O₅ K₂O
40 80 40

The local ag supply store has the following fertilizers on hand:

15-15-15
16-20-0
0-45-0 (triple superphosphate)

Is it possible to meet the 40-80-40 recommendation by mixing 2 or more of these together? If so, what proportions are needed, and what is the resulting fertilizer formula?

SOLUTION: The 40-80-40 recommendation has a 1:2:1 ratio. The 15-15-15 provides NPK in a

1:1:1 ratio. What's needed is to increase the amount of P by adding some 0-45-0 fertilizer. The easiest way to calculate the amounts needed is to set up a worksheet as follows:

N P₂O₅ K₂O.
100 kg 15-15-15 = 15 kg 15 kg 15 kg
X kg 0-45-0 = 0 kg 15 kg 0 kg
100 + X kg = 15 kg 30 kg 15 kg

This worksheet helps visualize the problem. It shows that in order to end up with a 1:2:] N:P₂O₅:K₂O ratio, we need to combine 100 kg of 15-15-15 with enough 0-45-0 to add 15 extra kg of P₂O₅. To figure out how much 0-45-0 is needed, divide 15 by 45%:

15 kg P₂O₅ needed/45% P₂O₅ = 33 kg 0-45-0

Now let's fill in the worksheet:

N P₂O₅ K₂O

100 kg 15-15-15 = 15 kg 15 kg 15 kg
33 kg 0-45-0 = 0 kg 15 kg 0 kg

133 kg = 15 kg 30 kg 15 kg

This shows that mixing 100 kg of 15-15-16 with 33 kg of 0-45-0 will produce 133 kg. of a fertilizer with a 1:2:1 ratio.

Determining the true formula of the mix: At first glance, it would seem that the formula of the mixture is now 15-30-15, but it isn't! What you've made is 133 kg of fertilizer containing 15 kg N, 30 kg P₂O₅, and 15 kg K₂O. But, fertilizer formulas are based on nutrient content in percent (i.e. kg of N, P₂O₅, and K₂O per 100 kg of fertilizer). Here's how to derive the true formula:

True formula = 15-30-15/1.33 = 11.25-22.5-11.25

CAUTION!: Not all Fertilizers can be Mixed

- Lime in any form should not be mixed with ammonium N fertilizers or urea. It will cause loss of N as ammonia gas.
- Lime should also not be mixed with any chemical fertilizer containing P, because it may convert some of the P into an insoluble, unavailable form.

Determining how much fertilizer is needed per area, per plant, or per length of row

Fertilizer recommendations are usually given on a per hectare (or per acre) basis. However, such figures are of little use unless you know how to determine the following:

- How much actual fertilizer is needed, given the size of the particular field?
- If the fertilizer will be applied using an LP (localized placement) method, how much fertilizer is needed per plant if the hole or half-circle method is used, or how much per length of row if it's banded? (These 2 application methods were covered earlier in this chapter.)

TABLE 9-5.

FERTILIZER MIXING GUIDE

Potassium
chloride
Potassium
sulfate
Ammonium
sulfate
Sodium
nitrate &
Potassium
nitrate
Calcium
nitrate
Urea Single % tr
superphosph
Potassium
chloride
x x x
Potassium sulfate x x x
Ammonium
sulfate
x x x
Sodium nitrate &
Potassium nitrate
x x x x x

Calcium nitrate x x x x o

Urea x x x x x

Single % triple
superphosphate

x o x

Mono- & di-
ammonium

phosphate

x o x

Lime o x x o

BLANK BOXES = Fertilizers which can be mixed.

BOXES WITH AN "X" = Fertilizers which can be mixed only shortly before use.
BOXES WITH A "O" = Fertilizers which cannot be mixed for chemical reasons.
EXAMPLES: Ammonium sulfate should not be mixed with lime.

Urea can be mixed with single or triple superphosphate shortly before use.

CALCULATING THE AMOUNT OF FERTILIZER NEEDED PER AREA

For Large Fields: Measure the field's dimensions and calculate the area. If its shape is not

rectangular, you may have to divide it up into triangles and rectangles and determine the area of

each. (The area of a triangle equals $1/2$ the base X the height.)

PROBLEM 5: Suppose soil tests recommended applying 250 kg/ha of 16-20-0 to grain sorghum at planting time. How much is needed for a field measuring 40 x 80 meters?

SOLUTION: One hectare = 10000 sq. meters

The field's size = 3200 sq. meters (40 x 80)

3200 sq. meters X 250 kg/ha/10000 sq. meters = 80 kg of 16-20-0 needed

For Small Plots: The metric system has some very handy shortcuts. A very useful one is:

100 KG/HA = 10 GRAMS PER SQ. METER

In other words, to convert from kg/ha to g/sq. meter, just drop a zero and change kg to grams!!

Here's why it works:

100 kg/ha = 100,000 grams/hectare

100,000 grams/10,000 sq. meters = 10 grams/sq. meter

PROBLEM 6: If the extension service recommends broadcasting 10-30-10 at 600 kg/ha for nursery seedbeds when no compost or manure are available, how many grams of 10-30-10 would be needed for a nursery seedbed measuring 1 X 5 meters?

SOLUTION: 600 kg/ha = 60 g/sq. meter

1 x 5 meters = 5 sq. meters

5 sq. meters x 60 g/sq. meter = 300 grams of 10-30-10 needed

CALCULATING THE AMOUNT OF FERTILIZER NEEDED PER PLANT

NOTE: The calculations below are based on open fields with evenly-spaced rows running across them. Where "intensive" gardening is used (beds with alleyways around them), another factor needs to be considered. We'll cover this after explaining the open-field calculations.

If using the half-circle or hole method of placement, the farmer will need to know how much

fertilizer is needed per plant (or group of plants if they're in "hills"). There are several ways of doing this, but most people agree that the following method is the simplest:

PROBLEM 7: Angelita is planning to plant a field of maize with rows 90 cm apart. She'll plant 3

seeds per hole with 60 cm between holes, using a planting stick. The extension office

recommends applying 18-46-0 at 150 kg/ha. If she uses the hole method of fertilizer placement, how many grams of 18-46-0 should each seed group receive?

SOLUTION: $150 \text{ kg/ha} = 15 \text{ g/sq. meter}$

$0.9 \text{ m} \times 0.6 \text{ m} = 0.54 \text{ sq. meters}$ of space belonging to each plant group.

$0.54 \times 15 \text{ g/sq. meter} = 8.1 \text{ grams}$ of 18-46-0 per plant group

NOTE: As you see, it's not necessary to know the field's size in order to arrive at the above answer. All that's needed is the rate per hectare and the in-row and between-row spacings. Of course, you need to know the field's area (or the total number of plants) to figure out how much fertilizer to buy.

PROBLEM 8: A communal garden project has run out of manure and is about to transplant cabbage on a field measuring 20 x 20 meters. The local extension office recommends applying 16-20-0 at 250 kg/ha using the half circle method. How much fertilizer should each plant receive if the rows are 60 cm apart with 40 cm between plants in the row?

SOLUTION: $250 \text{ kg/ha} = 25 \text{ g/sq. meter}$

$0.6 \text{ m} \times 0.4 \text{ m} = 0.24 \text{ sq. meters}$ space occupied by each plant

$0.24 \times 25 \text{ g/sq. meter} = 6 \text{ grams}$ of 16-20-0 needed per plant.

AMOUNT NEEDED PER METER OF ROW LENGTH

NOTE: The calculations below are based on open fields with evenly-spaced rows running across them. Where "intensive" gardening is used (beds with alleyways around them), another factor needs to be considered. We'll cover this after explaining the open-field calculations.

When banding fertilizer, farmers need to know how much to apply per meter of row length (or per row). As with per-plant dosages, there are several ways of calculating this, but the simplest and quickest method is shown below:

PROBLEM 9: Suheyla is about to apply an N sidedressing to her grain sorghum field. The recommendation is 200 kg/ha of 21-0-0 (ammonium sulfate). The rows are spaced 90 cm apart, and she plans to apply the fertilizer in a band running down the middle of each row. How many grams of 21-0-0 should be applied per meter of row length?

SOLUTION

STEP 1: $200 \text{ kg/ha} = 20 \text{ g/sq. meter}$

STEP 2: All the fertilizer in a meter of row length will be confined in a band. If you can calculate the area belonging to that one meter of row length, you can figure out the dosage per meter:

Area belonging to 1 meter of row length = 1 meter of length \times 0.9 m of width = 0.9 sq. meters

STEP 3: $0.9 \text{ sq. meters} \times 20 \text{ g/sq. meter} = 18 \text{ g}$ of 21-0-0 meter.

ADJUSTING CALCULATIONS FOR THE BED-AND-ALLEY SYSTEM

All the above dosage calculations were based on the open-field system of crop spacing where the rows are spaced equally across the field. (Both systems are explained and illustrated in Chapter 4.) However, if you use the same assumption when calculating dosages for intensively-grown crops (bed-and-alley system) you'll end up significantly shortchanging the plants on fertilizer. Here's why:

- In the intensive system, vegetables are grown under very close spacings within beds (flat, raised, or sunken) that are separated by alleyways used for all foot and equipment traffic.
 - Since virtually all root growth takes place in the soil within the beds, no fertilizer (or water) should be applied to the alleys.
 - The fertilizer recommendation per hectare is the same for both systems, BUT this means that the dosage per plant, per meter of row length, and per planted area (i.e. beds only) will be higher in the intensive system to make up for the fact that no fertilizer is applied to the alleyways.
 - Another way of explaining this is that plants grown under the intensive system are spaced much more closely than when grown on an open-field basis. Because of this, more fertilizer is needed per sq. meter of actual bed. Since alleyways aren't fertilized, the amount of fertilizer per hectare ends up the same for both systems.
- NOTE: You may think that water rates need to be similarly increased per sq. meter, but not so. That's because the high plant densities under bed-and-alley cropping shade more of the soil surface and thus lower evaporation losses of water; this helps compensate for the increased usage caused by the higher plant density. Also, the plant leaves shade each other more, which lowers transpiration (actual plant usage).

Let's go over how to calculate fertilizer dosages for bed-and-alley cropping.

PER AREA (Bed-and-Alley System)

In the open-field system, 100 kg per hectare equals 10 grams per sq. meter. Now, in the intensive system you have 2 types of area: bed area (planted area) and alley area. This means that 100 kg/ha of fertilizer doesn't work out to 10 g/sq. meter of actual bed area. If you applied 10 g per sq. meter to all the bed area, you'd end up applying much less than 100 kg/ha, because of not fertilizing the alley area which can equal about 30-40% of the total area.

Let's run through a practice problem on how to adjust for this:

PROBLEM 10: Akbar has 10 beds each measuring 1 x 10 meters; they're separated from each other by alleyways 60 cm wide on all 4 sides. He is told to apply 12-24-12 at 300 kg/ha at planting and wants to know how much fertilizer to buy.

SOLUTION

STEP 1: 300 kg/ha = 30 g/sq. meter of total area (beds + alleys)

STEP 2: Determine the total area (beds + alleys) occupied by Akbar's plots:

It's accurate enough to assume that each 1 x 10 meter bed is separated from another by a 60 cm alleyway on each of its 4 sides.

Therefore each bed along with its associated portion of alley (half the width of each alley) measures 1.6 x 10.6 meters which equals 17 sq. meters.

10 beds x 17 sq. meters (bed + alley) = 170 sq. m

STEP 3: Calculate the amount of 12-24-12 needed for all the beds, based on the total area involved.

170 sq. m x 30 g/sq. m = 5100 g = 5.1 kg of 12-24-12 needed

STEP 4: Calculate the amount needed per bed:

5.1 kg are needed but will be applied only to the beds themselves, not alleys.

5100 grams/10 beds = 510 grams 12-24-12 needed per bed

Now you can see how much difference there is in dosages. If you had based the dosage on 30 g/sq. m and used bed area alone, each bed would receive 300 grams of fertilizer (10 x 30) instead of the 510 grams it really deserves!

PER PLANT (Bed-and-Alley System)

In this case, the easiest way to calculate the upwardly-adjusted rate is to count the number of plants on a bed and then divide that into the amount of fertilizer needed per bed as we did for Akbar's plot above.

PROBLEM 11: Suppose Akbar is planning to transplant cabbage on the beds above. He'll run 3 rows down the length of each bed with 40 cm between rows and 40 cm between plants in the rows. How much 12-24-12 should each cabbage transplant receive if he plans to use the half-circle method and the same rate per hectare (300 kg)?

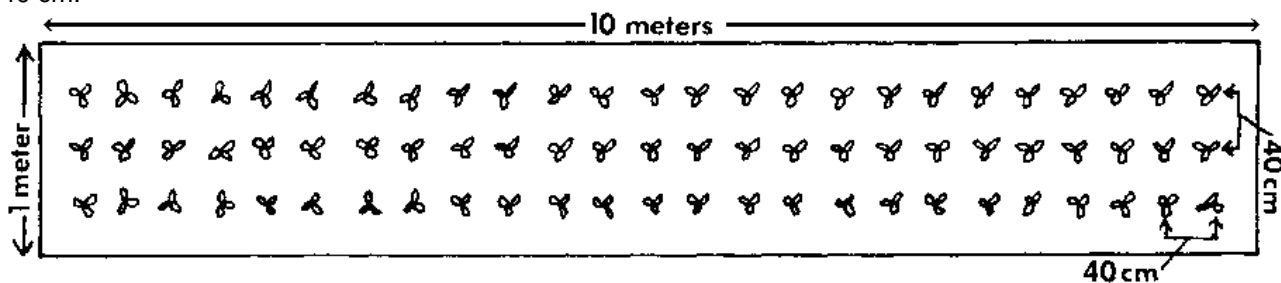
SOLUTION

STEP 1: Find how many cabbage plants will fit on each bed:

25 plants will fit in each row (24 spaces with 40 cm between them, with the first and last plant

being 20 cm from the bed's end). 75 total plants/bed. (See Figure 9-3.)

FIGURE 9-3: A 1 x 10 m bed can accommodate 75 cabbage plants spaced 40 cm x 40 cm.



STEP 2: Find the dosage per plant:

In the above problem, we determined that Akbar needs 510 g of 12-24-12 per bed.

510 g/75 cabbage plants = 6.8 g 12-24-12 per plant

Now, let's compare this dosage to that obtained from using open-field system math calculations

as in Problems 7 and 8 a few pages back:

300 kg/ha = 30 g/sq. m

0.4 m (40 cm) X 0.4 m = 0.16 sq. m of space belong to each plant

0.16 x 30 g/sq. m = 4.8 grams (too little)

If Akbar applied 4.8 g per plant, each bed would receive only 360 g (instead of 510 g), which would work out to about 212 kg/ha instead of the recommended 300 kg/ha. (If each bed occupies 17 m² (including alleyway area), there would be about 588 beds in a hectare; 588 x 360 g = 212 kg.)

AMOUNT PER METER OF ROW LENGTH (Bed-and-Alley System)

In this case, the simplest method is to find the amount of fertilizer needed per bed as in Problem 10 and divide this by the number of rows per bed.

PROBLEM 12: Suppose Akbar decides to plant leaf lettuce on the 10 beds in Problem 10 g in rows 20 cm apart running the short way (i.e. 1 meter long rows). Using the same fertilizer rate

(300 kg/ha of 12-24-12, how much should be applied per meter of row if the band method is used?

SOLUTION

STEP 1: Find out how many rows will fit on each 1 x 10 m bed:

50 rows with 49 row spaces each of 20 cm will fit on a 1 x 10 m bed. Each of the 2 end rows will be 10 cm in from the bed's edge.

STEP 2: Determine the dosage per meter of row (i.e. one row in this case):

From Problem 10, we know that 510 grams are needed per bed, so:

510 grams/50 rows = 10.2 g of 12-24-12 per one meter of row length

Again, let's compare this intensive system dosage with that obtained by using open-field calculations as in Problem 9:

300 kg/ha of 12-24-12 = 30 g/sq. meter

0.2 m (20 cm) X 1 meter = 0.2 sq. meters space belonging to each meter-long row

0.2 sq. meters x 30 g/sq. m = 6 g of 12-24-12 per sq. m (too low)

Converting fertilizer dosages from a weight to a volume basis

TABLE 9-6

FERTILIZER WEIGHT TO VOLUME COMPARISONS

Grams of Fertilizer Equal to:

Fertilizer 100 cc(ml) 1 Level Tablespoonful (15 cc)

Ammonium sulfate 108-120 g 16-18 g

Ammonium nitrate (prilled) 85 g 13 g

Ammonium nitrate (granulated) 100 g 15 g

Urea 75-79 g 11-12 g

16-20-0 98-104 g 15 g

18-46-0 93-108 g 14-16 g

Potassium chloride (0-0-60) 100-120 g 15-18 g

Single superphosphate 109-111 g 16-18 g

Triple superphosphate 100-112 g 15-17 g

Most other NP and NPK fertilizers 93-110 g 14-16.5 g

As shown by the above dosage problems, the amount of chemical fertilizer needed per plant or per meter of row is surprisingly small, usually ranging from 5-30 grams. To assure accuracy and cost-effectiveness, farmers should not attempt to estimate such small amounts. However, since few farmers or gardeners have easy access to accurate scales, it's very helpful if to convert the fertilizer dosage from weight to volume. This doesn't mean simply converting grams to cubic centimeters, either. The dosage should be given in terms of a commonly available volume measure such as a:

- Juice can
- Tuna fish can
- Bottle cap lid
- Match box
- Spoon size commonly used in the area

This can be done by using a gram scale (check the post office or a pharmacy) to measure the densities of the common fertilizers available and comparing them to water (1 gram = 1 cc or 1 ml). Then you can measure the volume of commonly available containers like those above and calculate how many grams of fertilizer they hold.

Fertilizers vary a lot in their density, depending on type, brand, and moisture content. If no scales are available, use Table 9-6.

Here's a practice problem for converting fertilizer weight to volume:

PROBLEM 13: How many grams of urea would a 120 cc juice can hold?

SOLUTION: 100 cc of urea weighs 74-79 grams.

$(120 \text{ cc}/100 \text{ cc}) \times 74\text{-}79 \text{ g} = 89\text{-}95 \text{ g}$ of urea in one juice can

Chapter 10: Fertilizer guidelines for specific crops

This chapter gives specific guidelines for using organic and chemical fertilizers on the following crops:

CEREALS PULSES ROOT CROPS VEGETABLES

Maize Beans Cassava (Manioc) Direct-planted

Millet Cowpeas Potatoes Transplanted

Sorghum Peanuts Sweet potatoes

Rice Soybeans

FRUIT CROPS TROPICAL PASTURES

Bananas Grasses

Mango Grass-legume pastures

Papaya

Cereals

Cereals belong to the Grass Family (Gramineae). Although relatively low in protein (7-14%) compared to pulses (20-39%), cereals supply about half the protein in the typical Third World diet, since they're eaten in large amounts. Per capita cereal consumption in the developing countries averages about 450-500 grams a day. Of the cereals listed above, millet is the most heat-and drought-tolerant, followed by sorghum.

NOTE: For more specific information on cereals, consult the PC/ICE Traditional Field Crops manual M-13.

MAIZE

Basic Facts about Maize

Mature, dry maize kernels contain about 9% protein. Yellow varieties also contain significant amounts of carotene which humans and animals can convert into vitamin A.

Depending on the variety and temperature, maize reaches physiological maturity (the stage where the kernels have ceased accumulating dry matter like starch and protein) in about 90-130 days after seedling emergence when grown in the 0-1000 m zone in the tropics. At elevation" above 2200 m, the growing period may be as long as 8-12 months.

The main difference between an early (90-day) and late (130-day) variety is in the length of the vegetative period (plant emergence to tasseling) which will vary from about 42 to 70 days. The reproductive period (tasseling to maturity) for both types is fairly similar (about 50-58 days). The tassel emerges about 1-2 days before it begins to shed pollen. The silks emerge from the ears 23 days after pollen shedding has started. Pollen shedding lasts 5-8 days, and most silks are pollinated the same day they emerge. Maize is cross-pollinated (i.e. 95% or more of the kernels on an ear are pollinated by other maize plants). Under favorable conditions, all the maize ears will have silked within 3-5 days. Shortage of pollen is rarely a problem; poor ear fill or skipped kernels are almost always caused by delayed silk emergence or by ovule abortion, both of which are caused by drought, overcrowding, or a shortage of N or P.

Maximum nutrient and water uptake occurs during the period from about 3 weeks before to 3 weeks after pollination. By silking time, maize has taken up 65% of its N, 50% of its P, and 75% of its K. Pollination is a very critical time and is readily affected by stress. Just 12 days of wilting during this period cuts yields by up to 22%, and 6-8 days by up to 50%.

At physiological maturity, the kernels still contain about 30-35% moisture which is too wet for spoilage-free storage (except in the form of dehusked ears stored in a crib). Most small farmers allow the maize to continue drying in the field on the stalk for several or more weeks before harvesting.

A large ear of maize may have 1000 kernels, but 500-600 is normal. Any shortage of water, nutrients, or sunlight during the first few weeks of kernel development usually affects the kernels at ear's tip first, making them shrivel or abort.

Most tropical and subtropical maize varieties commonly produce 2-3 useful ears per plant under good conditions.

In contrast, most U.S. Corn Belt types are single-eared. One advantage of multiple-eared varieties (often called prolifics) is that they have some built-in buffering capacity in the event of adverse conditions and can still be able to produce at least one ear.

Yields: Average yields of shelled grain (14% moisture) under varying conditions are shown in Table 10-1.

TABLE 10-1

Maize Yields

kg/hectare

Top farmers in U.S. Corn Belt 10,000-13,500

U.S. Average 5700

Average for Third World 800-1500

Feasible yield for small farmers using improved practices with adequate moisture

4000-6000

Fertilizer Response of Maize

Maize responds well to both organic and chemical fertilizers. However, since it's usually a staple crop grown on larger fields, most farmers are unlikely to have enough organic fertilizer to meet maize's nutrient needs. Chemical fertilizer can give excellent returns if used as part of an appropriate package of practices.

Evaluating fertilizer response: When starting from a low yield base of 1000-1500 kg/ha, yields of

shelled maize should increase by about 25-50 kg for each kg of N applied up to a yield of about 4000-5000 kg/ha. Above this, the response usually drops below this ratio. The response formula

applies to rates within the “low-medium-high” ranges of the Table 94 in Chapter 9. Such yield boosts will be obtained ii:

- Other nutrients like P and K are supplied as needed, soil moisture is adequate, a responsive variety is used, and there are no serious limiting factors such as insects, diseases, weeds, poor drainage, or excessive soil acidity.
- The fertilizer is applied correctly and at the right time.

EXAMPLE: In 1975/76, 168 small farmers in Zaire took part in the Programme National Mais (PNM). Yields averaged 4700 kg/ha using a fertilizer rate of 64-45-30 (kg/ha of N-P₂O₅-K₂O). Given that average yields without fertilizer were about 1500 kg/ha, did the farmers get a good response?

SOLUTION: According to the response formula above, 64 kg of N should produce a yield increase of about 1600-3200 kg/ha for a total yield of 3100 (1600 + 1500) to 4700 (3200 + 1500) kg/ha. Since farmers averaged 4700 kg/ha, each kg of N increased the yield by 50 kg, a very good response.

N-P-K Needs of Maize: Use Table 9-4 in Chapter 9 as a guide. Maize and other Grass Family crops are more efficient K extractors than most other crops. On many loamy to clayey soils of volcanic origin, little or no K may be needed, but check to make sure. Research has shown that maize can effectively utilize up to 60 kg/ha of P₂O₅ when a localized placement method is used (band, hole, half circle).

Secondary Nutrients: Sulfur deficiencies in maize are very uncommon but most likely to occur in sandy, volcanic soils under high rainfall or in cases where low sulfur fertilizers have been used for several years (see Chapter 9). Magnesium deficiencies are also unusual except in very acid soils (below pH 5.5). Calcium deficiencies are very rare but can occur in extremely acidic soils.

Micronutrients: Except for zinc, maize isn't especially susceptible to micronutrient deficiencies (zinc, copper, iron, manganese, boron, molybdenum). Except for Mo, they're most likely to occur above a pH of 6.8 or in sand, or organic soils (peats). Large applications of P may lower zinc uptake below the critical level in low zinc soils. To confirm a zinc deficiency, spray 10-20 plants with 6 cc of zinc sulfate dissolved in 4 liters of water plus 3-6 cc of liquid dishwashing detergent as a spreading agent (wetting agent). If zinc is lacking, new leaves will be a normal green when they emerge. (See Chapter 9 for suggested zinc rates.)

Hunger Signs in Maize: See Appendix E.

Chemical Fertilizer Application Guidelines

Apply about 1/3-1/2 of total N at planting time, along with all the P and K. Sidedress the remaining N at knee-high stage (4-6 weeks after seedling emergence). Where leaching losses are likely to be high (heavy rainfall, sandy soils), it's best to split the total N into 3 applications: 1/3 at planting, 1/3 at knee high, 1/3 at tasseling. Under such conditions, leaching losses of K can also be a problem, so it may be advisable to split the K dosage into 2 applications (at planting and at knee-high stage).

First application: Use an NP or NPK fertilizer with a ratio that allows all the P and K to be applied, but only 1/3-1/2 of the total N. Apply the fertilizer at planting time, using one of the localized placement methods covered in Chapter 9. Don't broadcast the fertilizer. If furrow irrigation is used, be sure to place the fertilizer below the high-water mark (see Fig. 9-1 in Chapter 9).

NOTE: If the NP or NPK fertilizer is band-applied, low to moderate rates can be placed in the same furrow right along with the seeds. Don't apply more than 200-250 kg/ha of 16-20-0 or 14-14-14 (or their equivalent); nor more than 100-125 kg/ha of 18-46-0 or 16-48-0 (all-ammonium

phosphate; it releases some free ammonia which can injure seeds if placed too close).

Nitrogen Sidedressing Recommendations for Maize

- The remaining N can be applied in one or two sidedressings, depending on the potential for leaching. Under heavy rainfall or on very sandy soils, 2 sidedressings are best. If one sidedressing is made, it's best applied when the plants are knee-high (about a month after emergence in warm weather). If needed, the second sidedressing should be made at tasseling time.
- Use a straight N fertilizer like urea (45% N), ammonium nitrate (33% N), or ammonium sulfate (21% N). (These 3 are compared in Chapter 9.)
- Deep placement of the sidedressed N isn't necessary and might also cause injurious root pruning. Try to get it down 2-3 cm deep, which is enough to prevent ammonia loss (especially a problem with urea) or wash-out by heavy rainfall on sloping soils. It can be banded right down the row middles, because roots from adjacent rows have already met and crossed each other by knee-high stage. (If the row middles are heavily compacted, root growth may not extend to them; in this case, place the band about 30 cm out from the row.)
- If labor or time is short, every other row can be sidedressed at double the rate.
- If furrow irrigation is used, follow the special placement guidelines mentioned above.

Some Guidelines for Plant Population and Spacing

Overly high populations cause increased lodging (tipping over), barren stalks, unfilled ears, and small ears. Overly low densities will lessen fertilizer response. The ideal plant population varies with the variety and growing conditions (especially available moisture). Check with the local ag extension service for population recommendations. Table 10-2 provides some suggested population guidelines.

TABLE 10-2

Suggested Plant Population for Maize

Recommended Plant Populations*

Per Hectare Per Acre

Low fertility and/or moisture 15,000-26,000 6000-10,000

Adequate fertility & moisture 35,000-45,000 14,000-18,000

Adequate moisture, high fertility (100+ kg/ha N), top management, and use of a responsive variety adapted to high populations

45,000-60,000 18,000-24,000

*To achieve these densities, overplant by 15-20% to allow for the actual germination percentage of the seed and for plant mortality.

Maize has a lot of buffering capacity as far as yield response to plant population. A density 40% below optimum may lower yields by only 15-20%, because the plants respond to the greater amount of space by producing more or larger ears.

Ear size is a good indicator of how adequate the population was for the particular growing conditions. Dry, dehusked ears weighing more than 280-300 grams usually mean that the population was too low and that yields could have been about 10-20% higher. Ear size of prolifics (multiple-ear varieties) won't vary as much with population changes; instead, the number of ears per plant will decrease as population is raised.

Plant spacing: Many small farmers using hand planting will sow 4-6 seeds per hole with the holes a meter or so apart. Although this reduces planting time and labor, yields suffer due to the competition for water, sunlight, and nutrients within a small area. A good compromise is to plant 2 seeds every 45-50 cm or 3 seeds every 60-68 cm with a between-row spacing of 80-90 cm. This gives a final stand of about 37,000-45,000 plants/ha. It usually isn't worth the extra effort to drill-plant the seeds (one seed every 22-25 cm) if planting by hand.

SORGHUM

Basic Facts about Sorghum

Mature, dry sorghum seeds contain about 8-13% protein. As with maize, varieties with a yellow endosperm (the major portion of the seed aside from the germ) contain significant amounts of carotene (converted to vitamin A by humans and animals) .

Adaptation: Sorghum tolerates a wide range of climatic and soil conditions. It's considerably more heat and drought-tolerant than maize and also withstands periodic waterlogging, without much damage.

Grain vs. forage vs. dual-Purpose sorghums: Most sorghums grown exclusively for grain are very short (80-150 cm). They have had "dwarf" genes bred into them to reduce plant height for more manageable machine-harvesting and a better ratio of grain to leaf. In contrast, forage sorghums are much taller and have smaller seeds and a higher ratio of stalk and leaves to grain. In much of the Third World where farmers need both grain and livestock feed, dual-purpose types are used that are intermediate in their characteristics. The stalks are also used for fencing and building materials.

Forage sorghums will yield several harvests by producing new stalks and leaves from the base of the plant after being cut. Even most grain sorghum varieties have this ability (called ratooning) and can produce 2 (sometimes 3) grain harvests in warm climates where the rainy season is long enough. A new root system develops in sorghum after each harvest. Grain yield of the ratoon crop is usually about half that of the first crop.

Leaves and stalks of young sorghum plants or drought-stunted ones under 60 cm contain toxic amounts of hydrocyanic acid (HCN or prussic acid). If livestock feed on such plants, fatal poisoning may result. The HCN content decreases as plants mature and is never a problem with the seed.

Growth Stages of Sorghum

Depending on the variety and temperature, grain sorghum reaches maturity in about 90-130 days within the 0-1000 m elevation zone in the tropics. However, some traditional, daylength-sensitive varieties can take up to 180-200 days, due to delayed flowering. As with maize, the main difference between a 90 day and a 130 day variety is in the length of the vegetative phase (seedling emergence to flowering). The reproductive phase (pollination to maturity) is about 30-40 days for all types. Sorghum plants initially grow much slower than maize during the first 3 weeks.

Yields: Grain sorghum has better yield stability over a wider range of growing conditions than maize. Grain yields are about the same as for maize when moisture is adequate, although high humidity increases the chance of fungal head mold. Under low moisture, sorghum will considerably outyield maize. Of the international research institutes, ICRISAT (see Appendix G) is the one most involved in sorghum production research.

Forage sorghum yields can be impressive. For example, small farmers in El Salvador can harvest 3 cuttings of forage sorghum (or sorghum-sudan crosses) during the 6 month rainy season. Total

wet-weight yields of 100,000 kg/ha have been obtained. The best time to harvest in terms of the trade-off between nutritive value (higher when plants are young) and yield (higher when plants are

near maturity) is from the earl, heading stage up until the seeds have reached the soft dough stage (i.e. when they have the consistency of soft dough).

Fertilizer Guidelines for Sorghum

As with maize, sorghum responds well to either organic or chemical fertilizers, as long as moisture isn't too limited and responsive varieties are used.

Sorghum has the same nutrient needs a. maize; however, as far as micronutrients, sorghum is most susceptible to iron deficiency rather than zinc. Unless special chelated forms of iron are used, soil applications are seldom effective. Deficiencies should be treated by spraying plants with a solution of 2.0-2.6 kg of ferrous sulfate in 100 liters of water with sufficient wetting agent to assure uniform leaf coverage. Begin spraying as soon as symptoms appear; several applications may be needed where deficiencies are severe (most likely at soil pH's above 6.8).

Sorghum seeds and seedlings are more sensitive to fertilizer burn than maize, so avoid fertilizer contact with the seed. Follow the same NPK guideline. as for maize. If more than one grain harvest is to be taken iron one planting, apply all the P and K at planting, along with about 30-60 kg/ha of N; sidedress another 30-50 kg/ha of N about 30 days later; after the first harvest, apply 30-50 kg/ha of N, followed by another sidedressing of 30-50 kg/ha 26-30 days later. Remember that actual N isn't the same as actual fertilizer (i.e. 50 kg actual N = 150 kg of 33-0-0).

MILLET

Millets are a group of small-seeded annual grasses grown for grain and forage and are the main staple food grain in regions of Africa and Asia, especially where hot and semiarid. Pearl millet (*Pennisetum typhoides*; syn. *P. glaucum*) is the type most widely grown and is the focus of this section.

Pearl millet is even more drought resistant than sorghum and will outyield other cereals (including sorghum) under high temperatures, marginal rainfall, low soil fertility, and a short rainy season. It is less susceptible than sorghum to stem-boring insects, but shares sorghum's vulnerability to bird feeding losses. It lacks sorghum's tolerance to flooding but withstands soil salinity and alkali conditions fairly well (see Chapter 12).

Pearl millet varieties are grouped into early (76-100 days) and late (120-200 days) types. The late types are very daylength-sensitive and won't head (flower) until near the end of the rains; this allows them to escape serious fungal head mold and insect damage.

Average Billet yields in West Africa range from 300-700 kg/ha and tend to be low due to marginal growing conditions and a relative lack of research efforts which have only recently begun. Under improved management, traditional varieties have yielded 1000-1500 kg/ha, and improved varieties up to 2000-3500 kg/ha. Of the international research institutes, ICRISAT (see Appendix G) is the one most involved with millet production research.

Fertilizer Response on Millet

Low soil moisture is a major factor limiting fertilizer response, and traditional varieties also tend to be less responsive. Studies in India by ICRISAT (Internal. Crops Res. Instit. for the Semi-Arid Tropics) showed that improved pearl millet varieties responded to N rates up to 160 kg/ha under adequate moisture, but that traditional types seldom responded well above the 40-80 kg/ha range. Follow the application methods for maize.

RICE

In terms of production, rice vies with maize as the number two cereal in the world after wheat. White rice (Billed to remove the bran layer) contains about 6.7% protein, while brown rice contains

about 7.4%, along with 4-5 times more beneficial fiber. The milling process also removes 70-80% of the levels of 22 vitamins and minerals, only 4 of which are replaced in the “enriched” brands.

Lowland (Flooded) vs . Upland (Dryland) Rice

Thanks to a very efficient air transfer system from the shoots to the roots, rice can grow under flooded conditions. It can also be grown without flooding on clayey soils with slow drainage where a high moisture content can be maintained. Flooded rice is usually grown with a 5-10 cm layer of water over the field, and yields are often 50-60% higher than dryland rice for several reasons:

- Flooding provides a more ideal temperature environment for the roots.
- It increases the availability of certain nutrients, especially P.
- It helps control weeds.

On the other hand, flooded rice production requires level land, plenty of water, a system of canals and dikes, and soils impermeable enough to prevent excessive water loss.

Transplanting vs. Direct Seeding

In the Third World, flooded rice is usually started out in a nursery seeded and then transplanted to the field about 1030 days later. Transplanting gives the plants a jump on weeds, and the confined nursery conditions “make it easier to care for and raise healthy seedlings. Transplanting also results in better spacing and survival in the field. On the other hand, direct planting hastens maturity by 710 days and eliminates the labor of caring for and transplanting the seedlings. However, direct planting allows more opportunity for rat and bird damage and makes weeding more difficult if the seed is broadcast (i.e. a hand-pushed rotary weeder couldn't be used).

Stages of Growth for Rice

Rice reaches maturity in about 110-150 days, though some native varieties that are daylengthsensitive may take 6 months or more. Here is a summary of growth stages:

- Nursery stage (for transplanted rice): 9-30 days depending on weather and type of nursery.
- Vegetative phase: The period from transplanting to 50-60 days after. The plants tiller during this stage, each plant producing 3-30 or more, depending on variety and spacing. About 50-75% of the tillers eventually produce productive heads of grain. (Tillers are additional shoots produced from the base of the plant.)
- Vegetative-lag phase: Occurs in late-maturing, daylength-sensitive types; some tillers die back. Much of the difference in time to maturity between early and late varieties occurs here.
- Reproductive phase: About 35 days and includes the period from Panicle initiation to flowering. Panicle initiation occurs about 60-70 days after seeding in the case of a 130 day variety; at this stage, the panicle (grain head) is just a millimeter long and is inside the stem.
- Ripening phase: From flowering to maturity; lasts about 30 days.

Nutrient Needs of Rice

High-N response vs. low-N response varieties: Nearly all native tropical rice varieties are low-N response types which are tall growing (over 1.5 m) and leafy. They respond to increasing N rates by growing still taller and producing more tillers (stems from the same plant). This leads to lodging (tipping over) plus a mutual competitive shading by the added tillers which reduces the number of seed heads. These varieties seldom respond well to more than 30 kg/ha of N.

Most of the temperate zone rice varieties are high-N responders and are short-stawed (90-120 cm) with a high percentage of seed-producing tillers. Many of the improved tropical varieties first

developed during the Green Revolution in the 1960's are crosses between the two types. They may show a profitable response to up to 100 kg or more of N per hectare.

N-P-K Needs: The N needs of rice depend a lot on whether a low-N or high-N variety is used. The P needs of flooded rice are unusually low compared with other grain crops, because flooding increases the soil's available P. Rates on flooded soils seldom exceed 40 kg/ha of P₂O₅. Responses to added K are most likely to occur on sandy soils. The rice straw itself contains about 80-90% of the plant's total K, so returning crop residues to the soil is a good way to recycle K. (The same is true for the residues of other crops.)

Secondary and micronutrient deficiencies are uncommon, although iron deficiency is occasionally found above a soil pH of 7.0.

Hunger signs in rice: See Appendix 8.

Organic Fertilizer Possibilities for Rice

Rice responds well to compost, manure, and green manure crops (see Chapter 8). The large volume of rice straw produced can be mixed with manure and composted. In the Philippines, IRRI (International Rice Research Institute) has obtained good results using 2 legumes (*Sesbania sesban*) and (*Phasolous lathyroides*) as green manure crops, plowing them under at flowering stage about 3 weeks before transplanting rice seedlings. This 3 week interval should be observed, since freshly incorporated green manure crops release toxic decomposition products (especially under flooded conditions) that can injure the rice seedlings. (For more specifics on these 2 legumes, refer to Appendix F.)

Blue-green algae (cyanobacteria): Free-living blue-green algae can thrive in flooded soils and fix significant amounts of N. In Egypt, India, and Burma, rice soils are often purposely inoculated with this algae.

Azolla is a low-growing, aquatic fern that has a symbiotic relationship with a type of blue-green algae called *Anabaena Azollae* that lives in its leaves and fixes N. It also has a high protein content, making it a potential feed source for fish and animals. Azolla forms a dense mat and can be grown either as a green manure or intercropped with flooded rice. Farmers in China and Viet Nam have used Azolla in their rice fields for centuries. Recently, it has been tried in other rice zones in Asia and Africa. Trials have shown that, where adapted, Azolla can provide from 30-100% of the N needs of rice, depending on the yield goal. To be successful, Azolla needs a high level of phosphorus, plentiful water, and temperatures not much above 30°C (86°F). It can be seriously attacked by insects, especially in the tropics. The use of Azolla is labor-intensive, because the fern produces no seeds; it must be continually maintained as a vegetatively-growing plant and transferred to rice paddies in this form.

Guidelines for Applying Chemical Fertilizers on Rice

Dryland Rice: Apply an NP or NPK fertilizer at or shortly before planting. If applied before planting, it can be broadcast and harrowed into the soil, although P rates may have to be several times higher to get the same effect as from localized placement. Deep placement of broadcast P isn't as necessary with rice, since many of the roots are found near the surface. Apply about 1/3 of the N at planting and sidedress the rest about 50-60 days later. Total N rates can go as high as 110 kg/ha when using improved varieties.

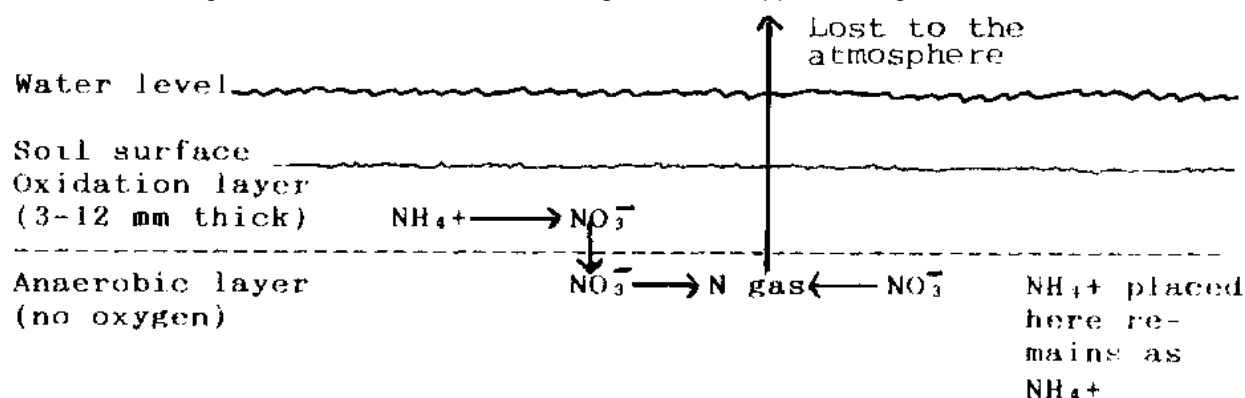
Transplanted, flooded rice: Most seedling nurseries aren't fertilized. If P is needed, an NP, or NPK fertilizer should be broadcast and harrowed in shortly before transplanting. Urea or an ammonium N fertilizer should be used to avoid losses by denitrification or leaching (see below). IRRI recommends applying half the N before transplanting and the other half about a week before

panicle initiation (about 60-70 days after seeding for a 130 day variety). On sandy soils' the N should be applied in 3 equal doses: 1/3 before transplanting, 1/3 20-30 days later, and 1/3 at panicle initiation.

Placement of N under Flooded Conditions: This is very important to understand in order to avoid heavy N losses:

- Flooded rice soils have two distinct layers: one with oxygen (aerobic layer) and one without oxygen (anaerobic layer). The aerobic layer is confined to the top 0.5-1.0 cm of soil, with the anaerobic layer beginning below it (see Fig. 10-1J).

FIGURE 10-1: Diagram of a flooded rice soil showing the fate of applied nitrogen.



- When chemical fertilizer N is needed, choose urea or an ammonium form of N, and be sure it's applied about 5 cm deep. This greatly reduces N losses from two sources: denitrification (conversion to N gas) and leaching. (Refer to Fig. 9-4.)
- Ammonium N and urea (which is converted to ammonium) can be held and retained by clay and humus particles. (See Chapter 6.) Nitrate N is readily leached.
- If ammonium N or urea are placed shallowly, they will be in the aerobic layer where there's enough oxygen for soil bacteria to change the fertilizer into leachable nitrate. The nitrate then moves down into the anaerobic zone from where it either continues leaching or is converted to N gas by oxygen-hungry bacteria and is lost to the atmosphere. (This conversion of nitrate to N gas is called denitrification and is discussed in Chapter 6 in the section on N).
- However, if the ammonium N or urea is originally placed in the anaerobic zone, it will remain as ammonium and be safe from leaching or denitrification.
- Numerous studies have shown that broadcasting N fertilizer over the flooded soil is only about half as effective as deeper placement in the anaerobic layer.

N Application Methods for Flooded Rice Soils

- When making the initial N application on flooded rice, the soil should be flooded within a couple days to prevent excessive conversion of ammonium to nitrate.
 - Urea is mobile for the first day or two after application until it's been converted to ammonium. Since this conversion requires oxygen, delay flooding the soil for 2 days after application to allow the conversion to occur.
 - Avoid off-and-on flooding of the field. Once the anaerobic layer begins drying out, it becomes aerobic.
 - Topdressed N (N broadcast over the water) can be worked into the soil with a hand-pushed rotary weeder.
 - Don't topdress with N when the leaves are wet. Granules that stick to the leaves will cause burned spots, and their N will be wasted if no rain occurs.
- As you can see, fertilizer use on flooded rice is especially complex, so be sure to consult reliable sources of information in your country.

Pulses (grain legumes)

Beans, cowpeas, peanuts, and soybeans are known as pulses, pulse crops, or grain legumes, along with other edible-seeded legumes such as chickpeas, pigeonpeas, mungbeans, winged

beans, lima beans, and English peas. As opposed to the cereals which belong to the grass family (Gramineae), pulses belong to the legume family (Leguminosae) whose members produce seeds in pods. Whereas the cereals are monocots, (seedlings emerge with one seed-leaf or cotyledon),

the pulses are dicots and emerge from the soil with 2 seed-leaves. In addition, pulses have 2 other notable characteristics:

- Their mature dry seeds contain 2-3 times more protein (20-39%) than the cereals (7-14%).
- They are partly to wholly self-sufficient in meeting their own N needs, thanks to a process called nitrogen fixation (also referred to as symbiosis).

Nutritional Value of Pulses

One cooked cup of most pulses provides about 15 grams of protein (soybeans have 20), compared to about 5 grams for most cereals. Non-pregnant, non-lactating vegetarian adults can easily satisfy their protein quantity and quality (amino acid) needs by consuming pulses and cereals in a ratio of 1 part pulse per 5 parts cereal (cooked basis). Recent research has shown that cereals and pulses still have a complementary effect on protein quality even if eaten several hours apart.

The mature seeds of pulses are also rich in B vitamins and are fairly good sources of iron. In some areas, particularly West Africa and S.E. Asia, the leaves of certain pulses such as cowpeas and winged beans are also eaten. As with most other dark-green leafy vegetables, pulse leaves are rich sources of many nutrients such as vitamins A and C, folio acid (folacin), calcium, and iron; they also contain a fair amount of protein. However, the leaves of some pulses, such as those of the yam bean (jicama; *Pachyrhizus erosus*) can be toxic.

Limiting Factors in Pulse Production

When both are grown under similar management, pulse yields are usually around half those of cereals for several reasons.

- They are more susceptible to diseases and insects.
- N fixation diverts some energy from the plant. (Don't worry, the trade-off is well worth it.)
- Compared to cereals, legumes use more of their N uptake to increase the protein content of the seed rather than to increase yield.
- Until recently, the amount of research on pulses was a distant second to that devoted to cereals.

Getting the Most out of Nitrogen Fixation

Most legumes have a symbiotic relationship with rhizobia bacteria (*Rhizobium* sp.) that live in the soil (non-legumes do not). If the correct strain of rhizobia is present, the bacteria will infect the roots soon after seed germination. The plant responds by converting some of its root hairs (tiny, hair-like protrusions from the roots) into nodules (bumps) to house the bacteria. The rhizobia live off sugars supplied by the plant and "fix" (capture) nitrogen from the soil air and convert it to a form (ammonium) that the plant can use. Thanks to nitrogen fixation, legumes are partly to wholly self-sufficient in meeting their own N needs as follows:

- Peanuts, cowpeas, yardlong beans, soybeans, mungbeans, pigeonpeas, chickpeas, winged beans, lablab beans (hyacinth beans; *Dolichos lablab*), yam beans (*Pachyrhizus erosus*), and vining (tropical) types of lima beans are wholly self-sufficient if the right strain of rhizobia bacteria is present in the soil.
- Common beans (*Phaseolus vulgaris*) and English peas have less efficient types of rhizobia and can satisfy only about half of their N needs.

- Legumes for pasture or for green manuring, such as clovers, tropical kudzu, stylo, and leucaena are wholly self-sufficient; the pasture legumes can even supply enough extra N to satisfy the needs of any pasture grass that might be intermixed with them (as long the, are intimately mixed and the legume makes up at least 40-60% of the mixture).

Rhizobia Cross-Innocation Groups: There are a number of different strains of rhizobia. A strain that forms effective nodules on one species of legume won't necessarily do the same on another. Fortunately, there is a good deal of effective cross-innocation that occurs between a rhizobia strain and different legume species, as shown in Table 10-3.

TABLE 10-3

LEGUME RHIZOBIA GROUPINGS (Includes pulses and other legumes)

Cowpea Group

Cowpeas, yardlong beans, peanuts, mung beans, lima beans, pigeon peas, yen bean (jicama; *Pachyrhizus erosus*), kudzu, crotalaria, velvetbeans, lab lab bean (*Dolichos lablab*, phasey bean (*Phaseolus lathyroides*), siratro (*Phaseolus atropurpureus*), Townsville stylo (*Stylosanthes humilis*), sesbanias (*Sesbania bispinosa*, *S. grandiflora*, *S. sesban*).

Bean Group

Common beans (*Phaseolus vulgaris*), including kidney beans, navy beans, black beans, and pinto beans.

Soybean Group

All varieties of soybeans.

Pea and Vetch Group

Garden peas (sweet peas), field peas, lentils, broad beans (fava beans), vetches.

Strain-specific

Each of the following legumes usually require their own specific strain of rhizobia for the most efficient N fixation: winged beans, chickpeas (*Cicer arietinum*), greenleaf desmodium (*Desmodium intortum*), silverleaf desmodium (*D. uncinatum*), centrosema (*Centrosema pubescens*), and all varieties of perennial stylo (*Stylosanthes guyanensis*) except Schofield.

A NOTE ON LEUCAENA (*Leucaena leucocephala*): Although specific rhizobia strains are now available for leucaena, the Nat. Academy of Sciences states that innocation normally isn't needed as long as other legume trees such as Mimosa, Gliricidia, and Sesbania grow in the area.

When is innocation necessary?: Under some conditions, the seed of certain legumes should be coated with a commercial innoculant containing the correct strain of rhizobia before planting. On the hand, innocation usually isn't necessary in cases where a well-nodulated legume belonging to the sane rhizobia group as the intended crop has been grown on the land within the past 2-3 years. This is especially true for members of the cowpea rhizobia group. On the other band, the strain-specific legumes in Table 10-3 almost always benefit from innocation, particularly when grown on a field for the first time. Where commercial innoculants are readily available, some extension services recommend that farmers innoculate all efficient N-fixing legumes before planting, even when they or others of the same rhizobia group have been grown on the field recently; this is looked upon as cheap insurance.

How to inoculate legume seed: Commercial inoculant is a dark, peat-based powder which contains the living bacteria and comes in a sealed packet (check the expiry date). It should be

kept below 26°C (79°F) or in a refrigerator (but not frozen) until use. Place the seed in a basin and slightly moisten it with water to help the inoculant powder stick. (Adding a bit of molasses helps, too.) Mix the correct amount of inoculant with the seed, and plant it in moist soil within a few hours. Don't expose the inoculant or inoculated seed to direct sunlight for long or it may kill the rhizobia. Some fungicide seed treatments will kill the bacteria, too, as will applying acidic fertilizers like superphosphate in the seed furrow. If commercial inoculant isn't available, try nixing the seed with soil taken from a field that has well-nodulated plants belonging to the crop's rhizobia group.

How to check for proper modulation: Begin checking about 2-3 weeks after planting. Gently remove some plants from the soil (the nodules on some legumes such as soybeans are easily detached), and look for clusters of nodules, especial!, around the taproot. Soybeans and most legumes of the cowpea rhizobia group have round nodules varying in size from BB's (shot) to small peas. Other legumes may have irregularly shaped nodules. When cut open with a knife or fingernail, the inside of a nodule will be pink or reddish if actively fixing N. A greenish or white color may indicate an ineffective strain of bacteria. It's normal to find some nodules in a state of decay (each one live. for only a few weeks) with brownish interiors. Incidentally, the pink or reddish color is due to the plant's production of leg-hemoglobin (like our blood's hemoglobin) within the nodule; this compound effectively binds up and inactivates oxygen which would otherwise deactivate the enzyme complex essential for N fixation.

NOTE: Don't confuse rhizobia nodules with root knot nematode galls! Nodules can be detached from the roots; nematode galls are swellings of the actual root itself and are white and grainy inside.

Troubleshooting inadequate nodulation: The following factors can result in little or no nodulation, even if a commercial inoculant has been used:

- If a commercial inoculant was used, check the precaution mentioned above in the section on inoculation.
- Waterlogging or flooding of the soil may seriously reduce the rhizobia population.
- The rhizobia of soybeans and some other legumes of temperate zone origin, such as alfalfa and some clover, are sensitive to soil pH's below 6.0.
- Heavy nematode infestations will depress nodulation.

COMMON BEANS (*Phaseolus vulgaris*)

Basic Facts on Common Beans

Common beans are those types belonging to the botanical classification *Phaseolus vulgaris* and are grown largely for their dry, edible seeds. The major types are black beans, red and white kidney beans, and pinto beans. The term field beans is a broader one and refers to all types of beans within the genus *Phaseolus* such as lima beans (*P. lunatus*) and mung beans (*P. aureus*), and is sometimes broadened to include those of other genera like chick peas (*Cicer arietinum*).

Common beans are best suited to regions with yearly rainfalls of 500-1500 mm, although they will produce good yields with as little as 300-400 mm of rain if it occurs during the crop's growth. Common beans aren't well adapted to high rainfall conditions due to increased disease and insect problems. Compared with sorghum and millet, beans don't tolerate high heat or limited moisture very well. Good soil drainage is especially important, since they're prone to root rots. They usually grow poorly in very acid soils (below pH 5.6), because they are very sensitive to high levels of soluble aluminum and manganese. (Poor drainage also promotes manganese and aluminum toxicity.)

Spotting aluminum toxicity: Lower leaves of seedlings become uniformly yellow with dead margins; growth is stunted. If severe, plants may die shortly after emergence, but this can be confused with fungal root rot damage.

Spotting manganese toxicity: See Appendix B.

Growth habit and stages: Varieties can be bushy, semi-vining, or vining in growth habit. Time to first flowering varies from about 30-56 days after planting, depending on variety and temperature. In warm weather, early-maturing varieties can produce mature pods in as little as 70-76 days; late varieties take 90 or more days. Bush types usually mature all their pods at about the same time; on the other hand, vining types have an indeterminate growth pattern, meaning that pod maturity is not uniform and that the harvest period is spread out over several weeks or more. Indeterminate varieties can be especially advantageous where moisture conditions are unreliable, since pollination (adversely affected during drought) occurs over a much longer period than for bush types.

Yields: Bean yields in most of the Third World average around 500-700 kg/ha (mature, dry seeds). This compares with a 1600 kg/ha average in the U.S.

Nutrient Needs of Beans

Nitrogen: Beans are among the less efficient N fixers and will usually require some nitrogen; recommended N rates fall in the range of 40-80 kg/ha. Acid-forming fertilizers like ammonium sulfate and urea (see Chapter 9) may increase the likelihood of aluminum and manganese toxicities if banded near the row on very acid soils. In this case, it might be better to spread the N over a larger area.

Phosphorus: Beans have a high P requirement, and this is often the major limiting nutrient, especially, on soils with high P tie-up ability (see Chapter 6). Rates of 40-80 kg/ha P₂O₅ are common and should be locally placed. On soils with extremely high P tie-up capacity, rates as high as 200 kg/ha of P₂O₅ have been applied by banding.

Potassium deficiencies are less common in beans.

Magnesium deficiency may occur in very acid soils or those high in Ca and K. See Chapter 9 for recommended rates.

Micronutrients: Beans are most susceptible to manganese, zinc, and boron deficiencies. Varieties vary in their sensitivity (See Chapter 9 for recommended rates.)

When applying an NP or NPK fertilizer at planting, the band method is the most practical, but avoid fertilizer contact with the seeds; beans are rather susceptible to burn.

Like all crops, beans respond well to organic fertilizers when sufficient quantities are available.

COWPEAS (*Vigna unguiculata*; syn. *Vigna sinensis*)

Basic Facts on Cowpeas

Next to peanuts, cowpeas are the major pulse crop of West Africa in the 500-1200 a. rainfall zone but are grown in many other regions of the world, too. They have better heat and drought tolerance than common beans, but the dry seed doesn't store as well and is very vulnerable to weevil attack. Cowpeas grow well on a wide variety of soils but do require good drainage; they're also more tolerant of soil acidity than common beans. The yardlong bean (*asparagus been*; *Vigna sesquipedalis*) is a close relative and is widely grown in Asia and in parts of the Caribbean. Its soil

and climatic requirements are similar to those of the cowpea. Both crops can also be used for green manuring.

In some areas, such as West Africa, both the leaves and the seeds are consumed. The cooked leaves are rich sources of vitamin A (as carotene), vitamin C (if not overcooked), folic acid, calcium, and iron.

Cowpeas have much the same growth habit and yields as common beans. Their nutrient needs are also similar, except that cowpeas are very efficient N fixers and seldom require any N.

PEANUTS (Groundnuts)

Basic Facts on Peanuts

Peanuts are an important cash and staple crop in much of the Third World. Mature, shelled nuts contain about 28-32% protein and vary in oil content from about 38-50%. While the fat content of most other pulses ranges from about 2-11% of total calories (39% for soybeans), that of peanuts is a surprising 70%.

Peanuts have good drought resistance and heat tolerance and are especially well adapted to the semi-arid tropics. They can also be grown in wetter climates if leaf fungal diseases like leaf spot can be controlled and if planted so that harvest doesn't coincide with wet weather. Peanuts don't tolerate poor drainage but do grow well in acid soils. A pH around 5.5 is optimum, but peanuts will tolerate soils as acid as pH 4.8. Soils that crust or cake are unsuitable, since penetration of the pegs (see below) is hindered.

Stages of Growth for Peanuts

Flowering begins about 30-45 days after plant emergence and is completed in another 30-40 days. The flowers are self-pollinated and wither within just 5-6 hours after opening. A plant may produce up to 1000 flowers, but only about 15-20% actually produce a mature pod.

The peanuts themselves originate at the tip of pegs which are stalk-like growths containing an ovary (future peanut pod) at their tips. The pegs begin elongating from the flowers after pollination and start to penetrate the soil about 3 weeks later. After reaching a depth of 2-7 cm, the pods begin developing rapidly and reach maturity about 60 days after flowering.

The fruits don't all mature at once, because flowering occurs over 30-40 days. Harvesting can't be delayed until all the pods have matured or heavy losses will result from pod detachment from pegs and from premature sprouting in the Spanish and Valencia types.

Yields: Average yields in the Third World range from about 500-900 kg/ha of unshelled nuts, compared to the U.S. average of 2700 kg/ha. Feasible yields for small farmers using good management are in the range of 1700-3000 kg/ha, depending on rainfall.

Fertilizer Needs and Application Methods for Peanuts

Peanuts tend to give rather unpredictable responses to fertilizer and often respond best to residual fertility from previous applications to other crops.

A special note on organic fertilizers: Organic fertilizers are very appropriate for peanuts. However, in areas where the soil-borne disease white mold (*Sclerotium rolfsii*) is prevalent, farmers should not leave any organic materials (manure, green manure, crop residues) on the soil surface but work them in thoroughly. Surface organic matter serves as a breeding ground for this white mold fungus.

Soil pH: Peanuts grow best within a pH range of 5.3-6.5. Higher pH's increase the likelihood of manganese deficiencies, while very acid conditions favor manganese and aluminum toxicities.

Nitrogen and Nodulation: If the right strain of rhizobia bacteria is present, peanuts can usually satisfy their own N needs with 2 exceptions:

- In low spots that become waterlogged, the rhizobia may die off and the plants begin to turn yellow. An application of 20-40 kg/ha of N may be needed to carry the plants along until the bacteria become re-established in several weeks.
 - In some cases (mainly on light colored, sandy soils), 20-30 kg/ha of N applied at planting has seemed to help the plants along until the rhizobia begin to fix N about 3 weeks after emergence. This isn't widely recommended.
- Seed inoculation normally isn't needed if peanuts are sown on land that has grown peanuts, cowpeas, mung beans, or other members of the cowpea rhizobia group within the past 3 years. (Many legume weeds belong to this group, too.) If inoculating, be sure to use the correct strain of rhizobia. Refer to the introductory section on pulses for inoculation instructions.

How to check for proper nodulation: Refer to the introductory section on pulses.

Phosphorus and Potassium: Peanuts have an unusually good ability to utilize P and K left over from previous applications and don't often give a good response to direct applications unless soil levels are very low. There is good evidence that high K levels in the podding zone can increase the number of "pops" (unfilled kernels), due to decreased calcium availability.

Calcium: Peanuts are one of the few crops with a very high Ca requirement. Light green plants plus a high percentage of "pops" may indicate Ca deficiency. Calcium doesn't move from the plant to the pods, but each pod has to absorb its own needs. Gypsum (calcium sulfate) is used to supply Ca to peanuts, because it's much more soluble than lime and doesn't raise soil pH. The usual application where deficiencies exist is 600-800 kg/ha of dry gypsum applied right over the row itself (it won't burn) in a band 40-45 cm wide any time from planting till flowering.

Micronutrients: Boron and manganese are the most likely to be deficient. Borax (11% B) can be mixed with fungicide dusts or gypsum at the rate of 5-10 kg/ha of borax. Instead, plants can be sprayed with Solubor (20% B) at 2.75 kg/ha Solubor. Applications above these rates can easily injure plants.

For manganese deficiencies, manganese sulfate (26-28% Mn) can be band applied with the row fertilizer at planting at the rate of 15-20 kg/ha. Plants can be sprayed with soluble manganese sulfate at 5 kg/ha; use a wetting agent.

Hunger Signs in Peanuts: See Appendix E.

SOYBEANS

Basic Facts on Soybeans

Mature, dry soybeans range from 14-24% in oil and about 30-40% in protein. In the Western Hemisphere, soybeans are grown mainly for their oil which is used in margarine, cooking, and industry. The meal remaining after oil extraction is an important high-protein feedstuff used in livestock rations. Raw soybeans have a protein digestion inhibitor (a trypsin inhibitor) which must be deactivated by heating before they can be used for food or feed; this is done during the manufacture of soybean meal.

The largest areas of soybean production are in the U.S., Brazil, Argentina, China, and S.E. Asia. Their reputation as a high-protein crop (35-40%) has tempted many development workers to introduce them. However, be aware of the following potential problems:

- Local pulses may be better adapted to the area. soybeans prefer a pH of 6.0-7.0 and don't tolerate acid soils well. High rainfall and humidity encourage insects and diseases.

- As with some sorghums and millets, all soybean varieties are very daylength-sensitive and have a narrow range of adaptation north or south of their origins. Flowering and pod formation are stimulated by short day lengths. If a variety is moved to an area of shorter day length (i.e. toward the Equator), flowering and pod formation will begin while the plants are still very small, and yields will be poor.
 - While they are a very efficient N fixer, they require a specific strain of rhizobia different from those of other legumes. This strain (*Rhizobium japonicum*) is unlikely to be present in soils not previously cropped to soybeans; in this case, seed inoculation is needed.
 - Soybeans often have acceptance problems as far as taste. However, new preparation methods and innovative recipes have helped overcome this.
- Yields: The average soybean yield in the U.S. is about 2000 kg/ha with 2500-3000 kg/ha being common. A realistic yield goal for the tropics would be about 1800-2500 kg/ha.

Fertilizer Guidelines for Soybeans

Soybeans grow best within a pH range of 6.0-7.0. More acid soils depress the activities of its particular strain of rhizobia bacteria and can also cause manganese and aluminum toxicities, as well as molybdenum deficiencies (Mo is also needed by the rhizobia). Above pH 7.0, deficiencies of P and micronutrients (except Mo) are more likely.

Nitrogen: Soybeans can easily meet their own N needs if the right strain of rhizobia is present. Fertilizer N seldom gives an economic response on properly nodulated plants. Some sources recommend applying a small amount of N (25-30 kg/ha) at planting to get the plants off to a good start, but the research evidence is against this.

Seed Inoculation: Soybeans require a very specific strain of rhizobia. Unless soybeans have been grown on the same soil within a year or two and were known to be well nodulated (see under peanuts), the seed should be inoculated with soybean rhizobia called *Rhizobium japonicum*. (Refer to the beginning of the pulse section in this chapter for information on how to inoculate.)

Phosphorus and Potassium: Soybeans respond well to P and K where soil levels are very low. Like peanuts, response is less likely if soybeans follow a well fertilized crop. Rates of 30-60 kg/ha of P₂O₅ are common. Soybeans are heavy K users, and rates range from 30-100 kg/ha of K₂O. P and K can be applied in a band at planting about 5-7.5 cm (3-4 fingers-width) out from the seed row and 7.5 cm deep. Soybeans are sensitive to fertilizer burn when K is used (P doesn't burn).

Micronutrients: Although sensitive to manganese toxicity in very acid soils, soybeans are also vulnerable to manganese deficiency at pH's above 6.5. Follow the rates given for peanuts. Molybdenum is needed by both the plant and the rhizobia, but deficiencies occur only on acid soils. Liming the soil to a pH of 6.0 will usually correct deficiencies (as well as manganese and aluminum toxicities). Instead of liming, the seed itself can be treated with Mo at the same time it's inoculated. Add 15 grams of sodium or ammonium molybdate to one cup (240 cc) of hot water, and then add a bit of molasses or honey. Cool and then mix the solution with 25-30 kg of seed. Mix in the inoculant, and plant as soon as possible.

Root crops

CASSAVA (MANIOC)

Basic Facts on Cassava

Cassava is a drought-resistant tuber crop known for its adaptation to poor soils. It's the 4th most important energy source in tropics after rice, maize, and sugarcane. Though its roots are very low in protein, they are an excellent calorie source. In many areas, the leaves are also consumed (cooked) and are rich in protein (about 30% on a dry weight basis), vitamin A (as carotene),

vitamin C, and folic acid. They are also a fair source of iron and calcium. Two cassava leaves provide a child with enough vitamin A for a day and cook down to a volume of only 15 cc (1 tablespoon).

The tubers and the leaves contain varying amounts of toxic hydrocyanic acid (HCN, prussic acid). Varieties are grouped into "bitter" (high HCN) and "sweet" (low HCN) types. Even the tubers of the sweet varieties must first be detoxified by peeling (most of the HCN is in the peel), followed by cooking, roasting, or sun drying. The bitter varieties are often used for commercial starch and alcohol production since they tend to be better yielders.

Cassava roots are ready for harvest from 8-15 months after planting cut sections of the stem about 25-30 cm long. For pure stands, a density of about 10,000 plants/hectare seems to be best. Although the tubers store well in the ground if harvesting is delayed, they spoil within a few days, once dug. Harvesting of the leaves will decrease tuber yields which average about 9600 kg/ha. Experimental yields of 80,000 kg/ha or more have been obtained. On poor soils, under low-moisture conditions, yields drop to about 1000-2000 kg/ha.

Cassava is unusual in that it has no critical period after establishment where drought will greatly lower yields. Surprisingly the bulk of the plant's roots are quite shallow but have the ability to proliferate in response to moisture stress. It is considered to be potentially one of the most efficient carbohydrate (energy) producers under adverse farming conditions in tropical areas and is also a relatively low-management crop.

Fertilizer Needs of Cassava

Cassava has an unusually good tolerance for very acidic soils with their high levels of soluble aluminum which would injure other crops. Although it is well adapted to low-fertility soils, it responds very well to organic and chemical fertilizers. Some agronomists feel that cassava extracts large amounts of nutrients (esp. K) from the soil, which may lead to fertility exhaustion after several years of intensive cropping, unless nutrient additions are made. However, research has shown that, except for K, cassava actually uses fewer soil nutrients than other crops per unit of dry matter produced. It is believed that mycorrhizae root fungi (see Chapter 1) play an especially important role in aiding the cassava plant's uptake of P on low-P soils.

NPK Needs: Excessive N will favor leaf production over tuber growth, so recommended rates fall in the range of 50-120 kg/ha. P is the nutrient most likely to be deficient in much of Latin America, but N and K shortages are more common in Africa and Asia. Recommended rates of P₂O₅ range from 60-130 kg/ha. Cassava has one of the highest K needs of any tropical crop, and rates range from 60-150 kg/ha of K₂O. Split applications of K are often recommended, especially where leaching potential is high.

Application Methods: Apply all the P and K, along with about 1/3-1/2 of the N at planting. The band or half-circle method can be used; avoid broadcasting on soils with a high P tie-up capacity. The rest of the N can be sidedressed in 1-2 applications between 1 and 3 months after planting. (Under high rainfall, the K dosage should be divided into 2 applications.)

POTATOES

Basic Facts on Potatoes

Worldwide, potatoes rank 4th in total production after wheat, maize, and rice, although production in the tropics is often restricted by high temperatures. Potatoes are often erroneously maligned as a low-quality, "fattening" food. While not a rich protein source, they have twice the protein content of cassava or sweet potatoes, and the amino acid quality rivals that of meat. They are very low in fat (1%) and are a fair source of vitamin C. A 140 g potato (5 oz.) has about 100 calories

compared with 270 for an 85 g (3 oz>) hamburger. This portion will provide about 4-5% of the daily calorie needs for an adult, along with 6% of the protein, 35% of the vitamin C, 10% of the iron, 20% of the vitamin Be, and a number of other nutrients.

In recent years, potato production has made a rapid expansion into tropical and subtropical areas for several reasons. Potatoes produce more edible energy per unit of time than almost any other crop, including maize and cassava. They are in high demand throughout the Third World and command a good price.

One limiting factor is the high cost of production (about \$1000/hectare), largely due to the volume and cost of the required "seed" (whole or cut potatoes). Usually 1000-2400 kg/ha are needed. Recent innovative research led by the CIP (International Potato Center in Lima, Peru) has devised new methods of propagation such as true potato seed (TPS), tuberlets produced from TPS or leaf bud cuttings, and tissue culture from stem cuttings.

Adaptation: Potatoes prefer cooler temperatures and will withstand light frosts. The best yields are usually obtained in areas where the mean daily mean temperature (average of high and low) doesn't exceed 20-21 °C (68-70°F) during the tuber formation period. Higher temperatures depress tuber production, since the plants tend to respire (burn up) much of the starch they produce instead of storing it. (Higher temperatures are OK during early growth). The yield-depressing effects of high daytime temperatures can be partially offset by cool nighttime temperatures. Potato varieties vary a lot in their heat tolerance. Recent breeding work spearheaded by the CIP has led to the development of more heat-tolerant varieties.

Growth Stages: Most varieties mature in about 100-125 days after planting the seed pieces. Emergence occurs about 2-4 weeks after sowing, and tuber formation begins about 3 weeks later (it has nothing to do with flowering). Full maturity is often not attained due to defoliation by fungal leafspot diseases like early and late blight. Potatoes require more skill and care to grow than most other field crops and are prone to many leaf and tuber diseases.

Fertilizer Needs of Potatoes

Potatoes are heavy feeders and respond very well to organic and chemical fertilizers, especially since their root system is small and tubers develop over a relatively short time period. They prefer a soil pH of 5.0-6.5 and are fairly tolerant of acidity. One way of controlling potato "cab disease" (a soil fungus; *Streptomyces scabies*) is to maintain the pH below 5.5.

Nitrogen: Overfertilization with N favors top growth over tuber growth, but most improved varieties will show a good response up to 110 kg/ha of N or more. Recommended rates range from about 50-80 kg/ha for Third World small farmers.

Phosphorus: P increases the number rather than the size of tubers, shortens maturity, and improves quality. Rates as high as 100-200 kg/ha of P₂O₅ are recommended for low-P soils and should be banded, not broadcast.

Potassium: Potatoes have especially heavy K needs, and even high K soils may become depleted after a few years of potato growing. Rates for medium K soils run about 50-100 kg/ha of K₂O. with even higher amounts for low-K soils. At K₂O rates much above 50-60 kg/ha, potassium sulfate should be used instead of potassium chloride (muriate of potash), because excess chloride lowers the starch content and quality of the tubers.

Magnesium deficiencies are sometimes a problem in acid soils below pH 5.5. When liming, use dolomitic limestone. Epsom salts (magnesium sulfate) can be applied to the soil at 200-250 kg/ha, or plants can be sprayed with a solution of 2.0-2.5 kg of epsom salts in 100 liters of water.

Hunger Signs in Potatoes: See Appendix B.

Application Methods for Chemical Fertilizer: Apply 1/3-1/2 of the N and all of the P and K at planting in a band about 5-7.5 cm (3-4 fingers-width) to the side of the seed row and 6 cm below

its depth. Sidedress the regaining N about 40 days later in a band about 25-30 cm out from the

row. The N can be worked into the ground a bit by combining the sidedressing with a weeding or hilling-up operation.

SWEET POTATOES

Sweet potatoes are an excellent energy source and are also low in fat like other root crops. The orange-fleshed varieties are very high in vitamin A (as carotene). One average sweetpotato (5 cm x 12.5 cm) provides about half the daily adult requirement of vitamin C, along with twice the vitamin A needed (if orange-fleshed). In many areas, the leaves are also consumed either fresh or cooked and are good sources of vitamin A, vitamin C, folic acid, iron, calcium, and potassium; they also contain a fair amount of protein.

Unlike Irish potatoes, sweet potatoes are a ware-weather crop; the roots are ready for harvest in about 4-5 months. In the tropics, planting is usually done with vine tip cuttings about 30-40 cm long. About 2/3 of the cutting's length (at least 4 nodes) should be covered with soil and the remaining third left exposed. (Tubers originate from the buried nodes.) Cuttings are hardy and begin rooting in just 2-3 days. A recent study in Puerto Rico showed that pre-rooting the cuttings by holding them for 2 days before planting increased the number of tubers and the yield; however, removing the leaves from cuttings to reduce transpiration decreased yields. Plantings can also be started by planting "slips" (young plants produced by planting tubers densely in a nursery bed). Vine tip cuttings have the advantage of not spreading soil-borne sweet potato diseases.

Fertilizer Needs of Sweet Potatoes

Both organic and chemical fertilizers give good responses. Excessive amounts of N will favor top growth over root growth, so rates of 50-80 kg/ha are recommended. Phosphorus rates range from about 40-70 kg/ha of P₂O₅. Sweet potatoes are heavy K feeders; on low-K soils, rates of 80-130 kg/ha of K₂O are recommended. Boron deficiency sometimes occurs and can be treated by mixing 5-6 kg/ha of borax (11% boron) with the NPK fertilizer; this equals only 0.5-0.6 grams of borax per sq. meter. Higher rates may cause plant injury.

Apply 1/3-1/2 of the N and K at planting time, along with all of the P. Sidedress the remaining N and K in 1-2 applications about 1-2 months after planting. Use the band method at planting. If planting is done on high ridges, the NPK fertilizer can be applied in a band running right below the future plant row; the ridge can then be built right over it and will separate the fertilizer with a enough soil so that burning won't occur.

Hunger Signs in Sweet Potatoes: N deficiency causes the leaves to turn light green to yellow, and the vines become deep red. P hunger causes dark green leaves that have a purpling over the veins on the backside of the leaves. K hunger begins with a yellowing and bronzing of the leaf tips and margins which gradually moves toward the center. See also Appendix E.

Vegetables

Most vegetables are very low in calories but have a high nutrient density in terms of vitamins and minerals. The dark-green leafy vegetables like kangkong, bok choy, amaranth, and collards are excellent sources of vitamin A (as carotene), Vitamin C, B vitamins, calcium, iron, and potassium. (However, amaranth, spinach, Swiss chard, and beet greens contain oxalates which bind up much of their iron and calcium; they can be partially deactivated by cooking). Dark-green leafy vegetables also provide significant protein.

The deep-yellow and orange vegetables like cantaloupe, carrots, and Hubbard squash are excellent sources of vitamin A, vitamin C, and potassium. For example, one large carrot contains twice the adult daily requirement of vitamin A. Aside from preventing vitamin A deficiency which leads to blindness and death from infections, carotene is now known to play an important role in

preventing several type" of cancer.

The Asian Vegetable Research and Development Center in Taiwan is the international research center most involved with tropical and subtropical vegetable production. The AVRDC has developed a number of heat-tolerant varieties of cool-season vegetables like cauliflower and also work” on disease resistance and general production practices. (Bee Appendix G for the address.)

General Fertilizer Needs of Vegetables

Since most Third World small farmers grow vegetables on small plots, this is an ideal situation for using organic fertilizers (see Chapter 8), and responses are excellent. However, in cases where organic fertilizers are in short supply, chemical fertilizer can be used if resources permit and will usually be very cost-effective on well--managed plots.

NPK Needs: The kind and amount of fertilizer needed varies a lot with the soil, the vegetable, and other key factors covered in Chapter 9. Table 10-4 gives a range of NPK rates from a number of research and extension sources worldwide.

TABLE 10-4.

Common NPK Rates for Vegetables

Kg/ha			
N	P2O5	K2O	
Beets, carrots, onions	60-100	40-80	60-100
Cabbage, broccoli, lettuce, cauliflower	60-120	60-80	40-80
Cucumber, squash, melons	60-100	60-80	60-80
Peppers, eggplant	70-100	40-80	40-100
Bush tomatoes (determinates)*	60-120	60-140	60-120
Vining tomatoes (in-determinates) *	100-180	60-140	60-160

* Determinate tomatoes are short, bushy plants that have a short harvest period of about 2-6 weeks. Indeterminate tomatoes are tall-growing, viny plants that can produce fruit for up to 6-8 months or more, as long as water, temperature, pest control, and nutrients are adequate.

TABLE 10-5

Susceptibility of Vegetables to Secondary Nutrient Deficiencies

Nutrient Vegetables

Calcium Tomato, celery

Magnesium Cabbage, eggplant, pepper, tomato, cucumber, watermelon

Sulfur Asparagus, onions, and the Crucifer family (cabbage, collard, broccoli, turnips, bok choy, kale, cauliflower)

TABLE 10-6.

Response of Vegetables to Micronutrients When Soil Levels are Low.

Vegetable Manganese Boron Copper Zinc Molyb. Iron

Beets High High High Med. High High

Broccoli Med. Med. Med. -High High

Cabbage Med. Med. Med. Med. Med. Med.

Carrot Med. Med. Med. Low Low -

Cauliflower Med. High Med. -High High

Cucumber Med. Low Med. ---

Lettuce High Med. High -High -

Onion High Low High High High -

Radish High Med. Med. -Med. -
Tomato Med. High Med. -Med. -

* From Lorenz and Maynard, Knott's Handbook for Vegetable Growers, 2nd ed., 1980.

CHEMICAL FERTILIZER APPLICATION GUIDELINES FOR VEGETABLES

Direct-Planted Vegetables

The band method of application is very suitable for direct-seeded vegetables like turnips, radish, mustard, bok choy, leaf lettuce, spinach, Chinese cabbage, and okra. The half-circle method works well with cucurbits (cucumber, squash, etc.) and transplants. Apply all the P and K along with 1/3-1/2 of the N at planting; sidedress the remaining N in one or more applications, depending on time to maturity and harvest method. For example, leafy greens, like leaf lettuce, spinach, Swiss chard, and bok choy, can be harvested either all at once or picked a few leaves at a time over a month or two (new leaves keep emerging from the center). In the latter case, 2 or 3 sidedressings can be made at 3-week intervals.

Transplanted Vegies

Tomatoes, peppers, eggplant, cabbage, collard, broccoli, cauliflower, head lettuce, and onions usually do better if first started out in a nursery seedbed, seedbox, or small containers and then transplanted to the field 3-6 weeks later.

Nursery Seedbed or Seedbox: In most cases, manure or compost will supply enough nutrients for the nursery stage. (See Chapter 4 for how to prepare a nursery seedbox mix.) However, there are 3 cases where chemical fertilizer might be needed:

- If the soil has been heat sterilized before planting, there may not be enough beneficial bacteria left to convert the organic N in the manure or compost into available N. However, fresh manure has a good amount of available N.
- If the manure or compost is of poor quality due to poor storage and exposure.
- If plants become N deficient while in the nursery. Watering is often high enough to cause lots of leaching.

If NPK fertilizer is needed, broadcast the equivalent of 60-80 grams/sq. meter (600-800 kg/ha) of 10-20-10 or 10-30-10 and mix it thoroughly into the top 10-15 cm of soil. Don't exceed 60-80 kg/ha of N or plants may become overly succulent and more prone to damping-off fungus disease. Fertilizers with a 1:2:1 or 1:3:1 ratio work best since they allow you to apply sufficient broadcast P without exceeding N or K rates.

NOTE: Disregard the amount of NPK applied in the nursery when calculating NPK rates needed' from transplanting onward.

N Deficiency in the Nursery Seedbed: If the plants turn yellow from N deficiency, dissolve a straight N fertilizer in water and apply it over the bed at the rate of 30 kg/ha of N which equals:

15 grams ammonium sulfate (21-0-0) per sq. meter

10 grams ammonium nitrate (33-0-0) per sq. meter

7-8 grams urea (45-0-0) per sq. meter.

Water plants with plain water afterwards to wash off any fertilizer solution from the leaves. If plants are being "hardened" in preparation for field setting (usually done the last 7-10 days before setting), N fertilizer will be counterproductive.

Using a Starter Solution for Transplants: Pouring a liquid starter fertilizer solution around the base of the plants after setting them will help get things off to a good start. Manure tea (see Chapter 8) or chemical fertilizer can be used for this. If using chemical fertilizer, here are the guidelines:

- Since P is the nutrient most involved in stimulating root regeneration and development, choose a formula with a good ratio of P in it such as 12-24-12, 18-46-0, or 10-30-10. Some N is helpful too, since it helps in the uptake of N.
- Except for a few like 18-46-0, most granular NPK fertilizers dissolve poorly in water. Grinding or mashing is helpful and will improve solubility.
- Dosage: Mix up 8-15 cc of fertilizer per liter of water and apply about 1 cup (240 cc) around the base of each transplant after setting.
- The starter solution only supplies enough nutrients for the first week or so of growth; additional organic or chemical fertilizer will be needed.
- NOTE: As in the case of fertilizer applied to a nursery seedbed, this starter fertilizer application is not counted when calculating overall NPK totals.

Applying Solid Fertilizer at Transplant Time: Use an NPK fertilizer that supplies 1/3-1/2 of the total N and all the P needed. If leaching is likely to be high, only about 1/3-1/2 of the K should be applied. The half-circle method works very well for transplants and should be made about 7.5-10 cm (about 4 fingers-width) out from the stem and 5-10 cm deep.

How to Sidedress Nitrogen: Review the sidedressing guidelines in Chapter 9 before proceeding. Here are some more specific suggestions for vegetables:

- Long-duration crops like indeterminate tomatoes, eggplant, and peppers may require 3-4 or more sidedressings at 3-4 week intervals.
 - Medium duration crops like broccoli and cauliflower will normally need 1-2 at 3-4 week intervals.
 - Apply about 30 kg/ha of actual N per sidedressing as a rough figure. It's more accurate to subtract the at-transplanting dosage from the total N and then divide the result by the number of sidedressings needed.
 - Apply the N in a band or half circle about 20 cm out from the plant; cover it lightly with soil. (This can be done by weeding with a hoe following the application.)
- Tropical fruit crops (Banana, Mango, Papaya)

Fruit crops are often a very casual or neglected part of agriculture but can play several useful roles on small farms and in gardening projects:

- Nutrition: Fruits can be valuable sources of energy, vitamin, and minerals. Some like mango and papaya are rich sources of vitamin A (as carotene) and vitamin C. Citrus fruits and guava are high in vitamin C. Nearly all fruits provide large amounts of potassium, an important body electrolyte. Even the leaves of some types like jujube and papaya are eaten and provide vitamins A and C, 8 vitamins such as folic acid, and minerals such as calcium and iron.
- Income: Fruit crops can be a good income producer and merit inclusion in most gardening projects.
- Shade

- Other functions: Some like cashew and jujube (*Zyziphus mauritiana*) can be part of a living fence or windbreak.

BANANAS

Basic Facts on Bananas

An average size banana has about 100 calories and is about 70% water. Bananas are a fair source of vitamin C and are very high in potassium; they are excellent as a carbohydrate source but are low in protein.

Bananas vs. Plantains: Plantains are close relatives of bananas but larger and with a much lower sugar content when ripe. They should be cooked before eating.

The banana plant's stem is called a pseudostem, since it's really formed from rolled-up leaves growing out of a true stem located underground in the corm (i.e. a core is an underground stem). A new feat appears every 10 days until the terminal bud (flower) emerges at 7-8 months; harvest follows in about 80-90 days.

Most of the plant's roots are found in the top 15 cm of soil, though some penetrate 60 to 90 cm. The roots may grow out laterally as far as 5 meters. Lateral roots grow out from the main roots and are the only ones that absorb nutrients and water. Since these feeder roots are scarce close to the stalk, fertilizer should be applied about 60 cm or more out from the base.

Established plantings regenerate themselves by producing several "suckers" per mother plant; the mother plant produces just one crop. In establishing new plantings, either corms from suckers or the suckers themselves are used. "Sword" suckers which have slim narrow leaves are preferred for propagation; "water" suckers (broad, wide leaves) are considered to be inferior, due to smaller corms.

Adaptation: Bananas prefer a warm, moist climate with about 1500-2500 mm of rainfall fairly well distributed. They prefer full sun but have a slight tolerance to shade. Good drainage is important; the plants can tolerate only a day or two of flooding. High winds (above 65 km/hr) cause considerable damage by tearing leaves and uprooting plants. Although tolerant of a soil pH ranging from 4.5-8.0, bananas do best at about 6.0-7.5. Very low pH can promote Panama disease (a soil-borne fungus; *Fusarium oxysporum*).

Yields: A good bunch will contain 8 hands (fruit clusters) with 15 fingers (fruits) each and weigh about 20 kg. Yields range from about 10,000-30,000 kg/ha when planted as the sole crop.

Fertilizer Needs of Bananas

Bananas use high amounts of N and K, though their P needs are moderate. Bananas benefit from high levels of soil organic matter. The planting hole can be partially filled with rotted manure or compost. Locating a compost pile adjacent to banana trees will provide shade, and any leached nutrients from the pile will benefit the plants. Mulching around the plants is very beneficial.

Feasibility of Chemical Fertilizers: When bananas are grown in the back yard or as part of a mixed garden (see Chapter 8), there is seldom any need for applying chemical fertilizers. Compost and manure can easily satisfy the nutrient needs of the plants.

Nitrogen: N-deficient plants have a pale yellowish-green color. N stimulates faster growth, earlier flower emergence and maturity, greater leaf area, and increased fruit size. N recommendations range from about 150-350 kg/ha applied in 3-10 applications, depending on leaching potential. About 80 grams actual N per plant is considered the minimum for commercial plantings, and often 100-200 grams actual N is used. All the N should be applied before flowering, since it's important

to stimulate early rapid growth. Research has shown a good correlation between the area of the third leaf and total bunch weight. Later N applications seem to promote “openhandedness” of the

bunch. Where regular spraying with fungicides is done, N can be supplied foliarly using urea (600 grams urea per 100 liters water for plants 1-2 months old and up to 3 kg/100 liters on older plants. One study showed that 65% of the urea was absorbed through the leaves in just 25 minutes.

Phosphorus: P needs are relatively low compared with N and K. Most recommendations are in the range of 50-85 kg/ha of P_2O_5 or about 50-100 grams P_2O_5 per plant. P can be applied in one application at or near planting or at various times as part of an NPK fertilizer. P deficiency causes a premature drying of the lower leaves.

Potassium: Where deficient, added K greatly increases yields and pseudostem growth, improves fruit quality and storage life, and promotes disease resistance. Moderate K deficiencies cause yellowing around the outer edges of the leaves; more severe hunger causes the leaf tips to turn reddish-brown and die. K hunger is also associated with the disorder called "premature yellowing" of the leaves. Most recommendations range from 80-250 grams of K_2O per plant or about 110-380 kg/ha of K_2O . K can be applied in 3 or more applications, depending on leaching potential.

Magnesium: Deficiencies are common in acid soils, especially where high amounts of K are used. Applying 200-250 grams of dolomitic limestone per plant will cure deficiencies. Mg hunger produces a broad band of yellowing along the edges of the lower leaves.

Iron, Zinc, and Manganese deficiencies can occur at soil pH's above 6.8.

Molybdenum deficiency has occurred in Honduras on highly-leached acid soils. Raising the pH is often effective at controlling Mo deficiency if the soil is very acid; otherwise, Mo should be applied.

Application Methods for Chemical Fertilizers: Young plants should have the fertilizer applied in a 30-50 cm wide band around the plant, starting about 30-40 cm from the stem. The band can be moved out to about 60-90 cm from the stem as the plants grow. Cover the fertilizer with about 3-5 cm of soil, but be careful not to injure the shallow roots.

Associated Growing Practices for Bananas

Much banana growing by small farmers is done on a very casual basis. Diseases, nematodes, insects, and overcrowding are common. Don't count on fertilizer alone to boost yields under such conditions. Some possibly appropriate improved practices are listed below:

- Proper selection and preparation of planting materials. Trimming the cores and sterilizing them with hot water or chlorox and water will help control nematodes and diseases and prevent their spread to new ground.
- Mulching to suppress weeds, conserve water, and add organic matter.
- Pruning out the excess suckers.
- A spray program for insects and diseases.
- Cutting off the terminal bud and dipping the cut in a fungicide solution to prevent decay. This can add about a kilogram to bunch weight.
- Covering maturing fruits with clear polythene bags with air holes; it can speed up maturity by 2 weeks and increase yield up to 20%.

MANGO

Mango is a widely-adapted tropical and subtropical evergreen tree that can grow as tall as 15-25 m with a spread of up to 15 m or more (smaller dwarf varieties are also available). It is related to cashew, pistachio nut, and poison ivy. Mango does well on a variety of soils as long as drainage is good. It prefers an annual rainfall of at least 450-1000 mm distributed over at least 6 months but

likes a pronounced dry season for flowering and fruiting. It does well within a pH range of 5.5-7.5. Mango has fair drought-resistance, thanks to a very deep taproot.

One medium mango (200 grams) supplies more than twice the daily adult requirement of vitamins A and C along with about 150 calories of energy. The fruit can be eaten fresh, juiced, or made into preserves and chutney

Most of the world's mangos are grown from aseed, but the fruit tends to be stringy and variable in quality. The best varieties are produced by budding or grafting to disease-resistant rootstocks. Grafted varieties begin bearing at 4-5 years of age (seedling mangos take longer), and the fruit is ready for harvest about 100-140 days after flowering. They have an economic life as long as 4080 years. An average yield under good management is about 400-600 fruits/tree.

Fertilizer Needs of Mango

Mango responds well to organic or chemical fertilizers. Mulching around the trees is a very beneficial practice. Nitrogen helps stimulate flowering and vegetative growth and lessens the tendency of alternate bearing (fruiting every other year).

Where chemical fertilizer is used, yearly rates per tree run about 0.5-1.6 kg N, 1.5-3.2 kg P₂O₅, and 0.5-1.0 kg K₂O. The N should be split into 4-8 applications depending on rainfall; K should also be split where leaching potential is high (sandy soils, high rainfall). If more convenient, an NPK fertilizer can be applied in split applications. Micronutrient sprays of copper, zinc, iron, and manganese are applied where needed.

Application method: For young trees, chemical fertilizer is spread uniformly over the root area from near the trunk to 60-90 cm beyond the edge of the leaf canopy (called the drip line). To avoid root damage, work it on no deeper than 3-4 cm, and apply it evenly. P is utilized fairly well with this method. Unlike uniform broadcasting over the entire soil surface, this method confines it to a small area, somewhat like a localized placement method (see Chapter 9).

PAPAYA

Papaya is a short-lived, fast-growing perennial tree about 4-6 meters tall. It does well on most soils as long as drainage is good; it won't tolerate flooding for more than 48 hours. Papaya needs a minimum of 1000-2500 mm annual rainfall fairly well distributed; otherwise, supplemental watering is needed. It has a weak, hollow stem which makes it susceptible to wind damage. Papaya prefers a soil pH of about 6.0-7.0. It is susceptible to nematodes.

There are 3 kinds of papaya trees: male, female, and hermaphroditic, but flowers may change from female to male under stress. Male trees seldom produce, and their fruit is misshapen and of poor quality. Fruit production on female trees requires the presence of a male tree for pollination. Hermaphroditic varieties such as the Solo group are self-pollinating. (Solo papayas produce grapefruit-size fruit and are popular for the export market; however, all Solos except the Cariflora variety are very susceptible to ring spot disease and several other viruses which are common in Central America and the Caribbean. Cucurbits such as squash and cucumber are an alternate host for these viruses.)

Papaya is propagated from seeds which sprout in about 10-15 days and can be sown in pots or directly in the ground. Flowering occurs about 5 months later, and fruit is ready to harvest at about 9-11 months of age. Yield per tree is about 60-90 kg/year. Trees have an economic life of about 3-4 years.

Papaya fruits vary in size, shape, and color; the most common flesh colors are yellow or reddish. The outside skin ripens to a golden color, starting from the stem. One medium papaya (300

grams) supplies 100% of the daily adult requirement of vitamin A and 3-5 fold the daily vitamin C needs. It can be eaten raw or preserved. The leaves and the pulp of unripe fruit contain a good amount of an enzyme called papain, useful as a meat tenderizer and digestive aid. The leaves

can also be eaten and have all the benefits of other dark green leafy vegetables, being rich in vitamins and minerals (including calcium) and also in protein. In some areas, papaya leaves are used as a diarrhea remedy.

Fertilizer Needs

Like most crops, papaya will respond well to organic fertilizers. However, farm manure shouldn't be mixed with the soil in the planting hole since it is known to favor the development of Pythium root rot. Papaya responds well to a continuous supply of nitrogen; P and K help promote rapid growth and early flowering; K is especially important after flowering.

In Australia, 8-12-6 fertilizer is recommended at 700 grams/tree the first year and 900 1350 grams/tree in the following years. The dosage is split into 4 applications per year. In South Africa, 100 grams actual N is recommended per tree the first year and 200 grams per year after that; P2O5, is applied once at about 100 grams per tree (about 450 grams of 0-20-0).

Application method: The fertilizer should be broadcast in a wide band from near the trunk outward about 60-90 cm during the first 6 months, expanding to 1.5 meters as trees grow. Work it in shallowly 2-3 cm to avoid root damage. The P applied in this manner isn't subject to as much tie-up as with regular broadcasting, because it's still confined to a relatively small area.

Some hunger signs in papaya: Yellowing of the bottom. leaves may indicate N deficiency. P deficiency produces dark-green leaves with a reddish-purple discoloration of the leaf veins and leaf stalks.

Tropical pastures

During the wet season, well-managed tropical pastures can provide enough feed for normal growth of calves and beef cattle and for production of 1-2 gallons (3.75-7.5 liters) of milk daily per cow. Supplemental feeding with high-energy sources like maize, molasses, etc. will be needed for higher milk production or more rapid fattening. From 2.5-5 460 kg cattle or 3.75-7.5 275 kg stock (or about the same number of dairy cattle) can be carried per hectare. Once the dry season sets in, both the amount and feed value of the pasture seriously declines, and even well-managed pastures can usually satisfy only the maintenance requirements of cattle (no growth or milk production). Under irrigation or well-distributed rainfall, tropical pastures should be able to produce about 550-1100 kg of live-weight gain per hectare yearly without supplemental feeding.

FERTILIZER NEEDS

Tropical grasses like elephant (rapier), guinea, pangola, bermuda, pare, and star give excellent responses to fertilizer, especially N. However, if overall management of the pasture and animals is low, it's questionable whether chemical fertilizer would be cost-effective.

Nitrogen

N is the most important nutrient in terms of amount, and rates up to 300 kg/ha or more yearly may be profitable under good management and well-distributed rainfall (or irrigation). Aside from increasing the pasture yield, N also increases the protein content to varying degrees, depending on the amount applied, type of grass, rainfall, and stage of maturity at which the pasture is grazed.

To reduce leaching losses, N should be applied in several applications. In humid areas without a pronounced dry season' N is usually applied 4-6 times a year. In areas with a dry season, 3-4 applications should be made, all of them during the wet season, unless irrigation is used. Work in Puerto Rico has shown that applying 110 kg/ha of N to recently-grazed pastures 6-8 weeks before the start of the dry season will greatly increase the amount and nutritive value of the grass carried

over into the dry season. With this method, grazing should be deferred immediately following the N application until the dry season begins. Guinea grass produce. an especially good standing hay with this method.

If urea is used, up to 30-35% of its N may be lost as ammonia gas (refer to Chapter 9); this may be partly offset by urea's typically lower price compared to other N sources; if urea is applied within a few hours before rainfall or irrigation, ammonia losses will be minimized.

Phosphorus: P can be applied once a year, since it won't leach. Rates of 60-90 kg/ha of P_2O_5 are common.

Potassium: Up to 220 kg/ha of K_2O may be needed on low-X soils under intensive management and year-round grass growth. Grasses tend to take up K in excess of their needs, so it's a good idea to split the dosage into 2 or more applications to avoid this "luxury consumption".

Sulfur: A sulfur-bearing fertilizer should be included in the fertilizer program, especially on sandy soils under high rainfall. Ammonium sulfate, single superphosphate, and ammonium phosphate sulfate (16-20-0) are good S sources. It's a good idea to supply about 20 kg/ha of sulfur per year (60 kg. sulfate).

Calcium and Magnesium: Remember that urea or ammonium sources of N have an acid effect on the soil. Liming may be needed after a few years of continued N applications. Soils with a low exchange capacity (negative charge) will drop more quickly in pH. Lime can be broadcast over the pasture. Use dolomitic limestone, or supply magnesium in another form to avoid deficiencies. Cattle are very sensitive to Mg deficiencies which can be caused by applying high rates of K without supplemental Mg. In cases where both the soil and the liming material are low in Mg, it may be necessary to apply about 100 kg/ha of magnesium oxide or 400 kg/ha of magnesium sulfate (Epsom salts) yearly in 2 applications.

Micronutrients: Deficiencies aren't likely, except in very leached or sandy soils or at pH's above

7.0 (except for molybdenum).

Value of "Self-fertilization" of Pastures by Cattle

Roughly 80% of the NPK and other nutrients in the feed are returned in the manure, which would seem to make fertilizers largely unnecessary for pastures. However, animals do a poor job at uniformly distributing the manure over the pasture; research has shown that only about 15% of the pasture is actually covered per year under typical stocking rates. A good deal of the N is lost as ammonia gas or by leaching.

Grass-Legume Pastures in the Tropics

Temperate-zone legumes like alfalfa and most clovers aren't well adapted to tropical humidity or very acid soils. Unlike temperate-zone pastures, few tropical pastures contain legumes. Legumes can significantly improve the feed value of a pasture, because they're higher in protein than grasses; they also decline more slowly in feed value as they increase in height between grazings. Legumes can also supply all their own N as well as that needed by the grasses with which they're grown in association.

Relatively little research has been done with tropical pasture legumes, but things are improving. One problem is that most tropical legumes have trouble competing with the rapid growth rate of most tropical grasses and get shaded out. Some are sensitive to overgrazing or aren't very palatable. However, tropical kudzu (*Pueraria phaseoloides*), *Centrosema pubescens*, siratro (*Siratro atropurpureus*), and several others have been grown successfully in combination with tropical grasses like guinea, star, and molasses grass. Townsville stylo (*Stylosanthes humilis*) is a self-regenerating annual (it reseeds itself) that can be easily established and maintained with a variety of grasses. Leucaena (ipil-ipil, *Leucaena leucocephala*) is a perennial tree/shrub that can be grown in rows in a pasture and used for browsing. (These and other pasture legumes are described in Appendix F; leucaena is also discussed in the agro-forestry section in Chapter 8.)

Consult with a pasture specialist concerning recommended grass-legume mixes for your area.

Fertilizing Grass-Legume Pastures: Since the legume fixes enough N for itself and the grass, no N fertilizer is needed. In fact, adding N will favor grass growth and eventually shade out the legume. Adequate P and K as well as sulfur are needed to maintain a good proportion of legume to grass. Compared to grasses, legumes are weak K extractors and are also susceptible to molybdenum and boron deficiencies.

USE THE "PACKAGE" APPROACH FOR PASTURE MANAGEMENT

It takes much more than just fertilizer for successful beef and milk production. Other practices like good grazing management, good stock, disease control, weed control, supplemental feeding, and worming are just as important. Some of these are summarized below.

NOTE: The following data is not designed to make you qualified to work with cattle but, rather, to give you some initial background in this area to facilitate further investigation and discussion with cattle and pasture specialists in your country.

Rotation Grazing

As grasses regrow after being grazed or cut, they decline in feed value as they mature, especially in protein. Tropical conditions favor rapid grass growth and maturity, and most grazed grasses may be unable to supply enough protein after only 4-5 weeks, even when fertilizer N is used.

Under low-management conditions, cattle are usually continuously confined to one pasture at a low stocking rate. The pasture's rapid growth outstrips the cattle's ability to consume the grass before it's become overly mature and low in quality. For example, a study in Trinidad showed that the crude protein content of pangola grass dropped from 15% 10 days after grazing began down to 4.2% 42 days later (dry-weight basis).

Rotation grazing consists of dividing up the pasture into 4-6 paddocks and putting all the cattle in one paddock at a time. Each paddock should be of a size that allows the cattle to graze down the grass in 4-7 days before they are moved to the next one. About 3 weeks rest is needed between grazings to obtain sufficient regrowth. Longer periods may be needed during cooler weather and shorter periods during more rapid growth. Guinea grass should be grazed down to about 20 cm, and pare, elephant, and pangola down to 10-15 cm. N fertilizer can be applied after each grazing. Over-grazing will use up stored food reserves in the roots and weaken the stand.

Dry Season Feeding: Hay and Silage

Forage quantity and quality decline disastrously during the dry season. Cattle often lose a good part of their wet season weight gains during the dry months and may take 4-6 years to reach slaughter weight (360-550 kg). It's possible to reduce this to 2-3 years, largely through the use of hay or silage for supplemental dry-season feeding. Most low management cattle raisers in the tropics have too few animals per hectare to fully utilize all the lush wet season growth, but too many in terms of the scant amount of dry season forage. Making hay or silage out of the wet season surplus growth is one answer. Silage making is usually more feasible than hay making during the wet season. (About 2000 kg of water has to be evaporated from freshly cut grass in order to make 1000 kg of hay!) Peace Corps Volunteers in El Salvador helped to establish a successful silage program with small cattle-growers, using sorghum-sudangrass. Yields averaging around 100,000 kg/ha have been obtained from taking 3 cuttings during the 6-month rainy season. They have also made good-quality pangola, stargrass, and jaragua hay at the end of the rainy season.

Provide Minerals for Cattle

Except for salt, cobalt, iodine, and copper, livestock can usually get all their essential minerals

from well managed pastures. Salt licks containing trace minerals should be supplied. Young cattle need about 20 grams of salt per day and older ones about 30 grams. kidding 10 grams copper

sulfate and 10 grams cobalt sulfate per 16 kg. of iodized salt will provide a satisfactory mineral mix for cattle grazing on fertilized pastures.

Control Weeds: Weeds compete for "pace, water, light, and nutrients with pastures; some may be poisonous as well. Broadleaf weeds are the most common. Herbicides may be needed, but first be sure the particular chemical is registered for use on pastures; follow label instructions closely to avoid injury to the pasture or contamination of meat and milk.

Keep Animals Healthy: Cattle raisers should follow the recommended vaccination schedule for their area; brucellosis, anthrax, blackleg, and others may be needed. Periodic worming is also essential, as well as tick control.

FOR FURTHER INFORMATION: Several international research institutes such as Winrock and CIAT are involved in research/extension efforts with pasture and cattle management in the Third World. See Appendix a for their addresses.

Chapter 11: Liming soils

NOTE: The concept of soil pH and the factors influencing it are explained in Chapter 6.

The purpose of liming

Depending on the crop and OD soil factors, very acid soils may need to be limed to raise their pH and counteract the affects of excessive soil acidity. Very acid soils (below a pH of about 5.0-5.5) may adversely affect crop growth for several reasons:

- Aluminum, manganese, and iron all become more soluble with increasing acidity and may actually become toxic to plants at pH's below 5.5. Many varieties of beans and wheat are especially sensitive to aluminum toxicity, although the true "tropical" soils (see Chapter 1) tend not to release toxic amounts until the pH approaches 5.0. Manganese and iron toxicities can be serious, too, but tend to be more of a problem on soils that are also poorly drained.
- Very acid soils are usually low in available P and have an especially high capacity to tie up added P by forming insoluble compounds with aluminum and iron.
- Although very acid soils usually have enough calcium to supply plant nutrient needs (except for peanuts), they are likely to be low in magnesium, as well as sulfur and available molybdenum (Mo becomes increasingly insoluble as acidity increases).
- Low soil pH depresses the activities of "good-guy" soil bacteria and fungi, such as those that convert the unavailable, organic forms of N, P, and S to available mineral forms. One of the main reasons that soybeans, alfalfa (Lucerne), and many clovers do poorly on acid soils is that their particular types of N-fixing rhizobia bacteria have little tolerance for pH's below 6.0. (On the other hand, many of the rhizobia species associated with the more tropical legumes [e.g. peanuts, cowpeas, and kudzu] can function well at lower pH's.)

When is liming needed?

Most crops will produce satisfactory yields within a pH range of 5.5-7.5, though micronutrient deficiencies (except molybdenum) become more likely above pH 6.8. Some, such as soybeans and alfalfa, don't grow well below pH 6.0. Others, such as pineapple, rice, coffee, potatoes, sweet potatoes, and watermelon, are more tolerant of acid soils than other crops.

TABLE 11-1.

Satisfactory Soil pH's for Common Crops

Crop	pH Range*	Crop	pH Range*
Maize	5.5-7.5	Pineapple***	5.0-6.5
Millet	5.5-8.0	Banana	5.5-7.5
Sorghum	5.0-8.0	Potatoes**	5.0-7.0
Rice	5.0-7.0	Sweet potatoes	5.0-7.0
Wheat	5.5-7.5	Tomato	5.5-7.0
Beans	5.8-7.5	Cabbage	6.0-7.0
Soybeans	6.0-7.0	Lettuce	6.0-7.0
Peanuts	5.3-6.6	Onions	6.0-7.0
Cotton	5.5-6.5	Peppers	5.5-7.0
Tobacco**	5.5-7.5	Cucurbits	5.5-7.0
Sugarcane	6.0-8.0	Watermelon	5.0-7.0
Coffee	5.0-7.0	Alfalfa	6.2-7.8

* Most of the above crops may grow OK at pH's half a point above or below the ranges given, depending on sold factors and variety used.

** A pH slightly below 5.5 will help control potato scab and tobacco black rot.

*** Smooth Cayenne pineapple prefers a pH of 4.5-5.5.

How to measure soil pH

Portable Test Kits

You can check soil pH fairly accurately right in the field using a good quality liquid indicator kit or a portable electric tester. Read and follow the instructions carefully and be sure to measure both topsoil and subsoil pH since they're usually different. Even if the field's soil appears uniform in color and texture, check pH at several locations. Readings from the better quality kits like the Hellige-Truog are accurate within 0.2-0.3 pH units. Litmus paper kits don't work well. Soil labs measure pH as a routine part of soil testing.

CALCULATING HOW MUCH LIME IS NEEDED

Role of the Soils Lab

Portable kits won't tell you the full story. They can be useful for troubleshooting, but if you do find a soil whose pH appears to be too acid, the kit won't tell you how much lime to add or even if it's needed after all. Here's why:

- The amount of lime needed to raise soil pH by one unit varies greatly from soil to soil. In fact, one soil may require up to 5-10 times as much lime as another to achieve the same rise in pH, even though both have the same initial pH. This buffering capacity varies directly with the amount of negative charge (cation exchange capacity) a soil has. Only a soil lab can measure this. (Buffering capacity is explained in more detail below; exchange capacity was covered in Chapter 6.)
- pH isn't the only criterion for deciding if liming is needed. The soil's content of soluble aluminum (called exchangeable aluminum) is often even more important, and a portable pH test kit can't measure this. The amount of harmful soluble aluminum increases as pH drops, but some soils reach this point at a higher pH than others (i.e. 5.5 instead of 5.0). The soils lab can determine this.

Soil Exchange Capacity and liming Requirements

This is a concept worth understanding so let's go through it step by step:

- Soils have both an active and a reserve acidity. The active acidity is produced by the those hydrogen ions (H^+) floating around free in the soil's water, and it's what a pH test kit measures.
- However, for every free-floating H^+ ion, there may be thousands or more H^+ ions held (adsorbed) to the soil's clay and humus particles (remember, they're the only soil particles with a negative charge). These H^+ ions make up a soil's reserve acidity and can't be measured with a pH test kit.
- As the applied lime neutralizes the free-floating H^+ ions (active acidity), the huge reserve of H^+ ions held by the clay and humus particles start supplying H^+ ions to take the place of the neutralized ones.
- The higher the amount of clay and humus a soil has, the greater its negative charge and buffering capacity, and the more lime will be needed to obtain a given rise in pH.
- An important point: Don't get confused! In terms of true soil pH (active acidity), clayey or high humus soils aren't any more likely to be acid than sandy soils; but, they're more resistant to changes in pH (either upward or downward), due to their greater buffering capacity.
- "Tropical" vs. "temperate" soils: True tropical soils (old, highly-weathered red or yellow soils) usually need less lime than "temperate" soils (see Chapter 1) of the same texture to obtain an equal rise in pH. That's because true tropical clay minerals have a much lower negative charge than temperate types (see Chapter 1) and, therefore, less buffering capacity. Remember that both tropical and temperate clay minerals occur in the tropics.

What to Do if No Soil Lab is Available

As explained later in this chapter, applying too much lime to an overly acid soil can be worse than not liming at all, so a farmer needs to be somewhat precise. If reliable soil testing isn't available, there are 2 alternatives:

- Check with your local extension service to see if liming recommendations have been developed for the area's soils based on prior experience, soil type, and lab testing.
- Use a generalized liming recommendation table such as Table 11-3.

How to calculate the actual amount of lime needed

Whether you use the lab's or the table's recommendation, you and the farmer will need to make adjustments for the neutralizing value, fineness, and purity of the actual material being used.

Types of Liming Materials and their Neutralizing Value

There are 5 general kinds of liming materials:

1. Limestone (calcium carbonate): Usually the cheapest of all, since it's taken directly from the ground and crushed without further processing. It's non-caustic.
2. Dolomitic limestone (dolomite): Contains both calcium and magnesium carbonates. Often recommended if available, since liming with straight limestone can produce a magnesium deficiency. However, you can also supply magnesium in fertilizer form such as epsom salts (magnesium sulfate) which doesn't affect soil pH.
3. Burned lime or quicklime: Made by heating limestone or dolomite in a kiln to drive off the carbon dioxide to form calcium oxide (or calcium and magnesium oxide). It's very caustic but has the highest neutralizing value and is also more rapid-acting than limestone. It tends to form flakes or granules unless thoroughly mixed with the soil.

4. Hydrated or slaked lime (calcium hydroxide): Made by burning limestone or dolomite in the presence of steam. Like burned lime, it's rapid-acting but isn't used much by farmers due to its higher cost. Also very caustic.

5. Miscellaneous materials

- Where available, coral sand can be used as a liming material; it is basically calcium carbonate with varying amounts of magnesium. The Pacific Agric. Trade School on Ponape island in Micronesia recommends 2 shovelfuls (4.5 kg) per 9 sq. meters, but this dosage would vary considerably with the initial soil pH and the soil's buffering capacity.

- Wood ashes are a potent liming material; in fact, they can easily raise soil pH too high if used indiscriminately (much more than 300-450 cc/sq. meter yearly).

NOTE: Gypsum (calcium sulfate) is not a liming material; it is a neutral salt and will not raise pH. The use of gypsum to improve alkali soils is explained in Chapter 12.

As shown by Table 11-2, the neutralizing value of a liming material varies with type.

TABLE 11-2

Neutralizing Value of Some Liming Materials

(Based on 100% strength and compared to limestone)

Material Neutralizing Value

Limestone 100%

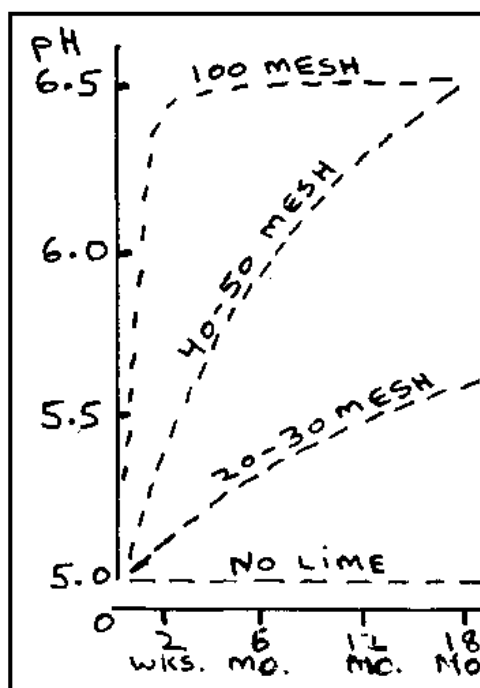
Dolomitic limestone 109%

Hydrated lime 136%

Burned lime 179%

Using Table 11-2: As an example, it would take 3580 kg of limestone to equal the neutralizing effect of 2000 kg of burned lime ($2000 \text{ kg} \times 179\% = 3580 \text{ kg}$).

FIGURE 11-1 The time required for lime to affect soil pH is greatly influenced by its fineness. In this greenhouse experiment at Oregon State University, it took more than a year for 20-30 mesh lime to raise soil pH just 0.5 units, but 100 mesh lime raised the pH by 1.5 units in just 2 weeks!



Fineness of Liming Materials is Important!

The time it takes a liming material to react with the soil depends a lot on its particle size. The finer the material, the more rapid the reaction. Note that even fine-textured materials may take 2-6 months to produce a significant rise in soil pH. Good-quality burned lime and hydrated lime are naturally fine, but crushed limestone and dolomite are often relatively coarse and will react more slowly.

Any liming material contains a mixture of different particle sizes. As shown in Figure 11-1, limestone passing through a 100 mesh sieve (holes are about 0.17 mm square or 1/150th of an inch) will react with soil acids in just 4-6 weeks if thoroughly mixed with the topsoil. Material passing through a 40-50 mesh screen may take 12-18 months to react completely. Material in the 20-40 mesh range will have reacted only 60% in 3 years and 10-20 mesh material only 30%. (See Figure 11-1).

TABLE 11-2.

	Amount of pure fine limestone needed per hectare to raise the soil pH from:	
	<u>pH 4.5 to pH 5.5</u>	<u>pH 5.5 to pH 6.5</u>
Sand or loamy sand	600 kg/ha	900 kg/ha
Sandy loam	1100 kg/ha	1550 kg/ha
Loam	1700 kg/ha	2200 kg/ha
Silt loam	2700 kg/ha	3100 kg/ha
Clay loam	3350 kg/ha	4200 kg/ha

Approximate Amount of Finely-Ground, Pure Limestone Needed to Raise the pH of an 18 cm (7") Layer of Soil as Indicated*

The amounts below are for true "tropical"-type soils. Since they have less buffering capacity than "temperate" soils of similar texture, the amount of lime needed is lower and might have to be increased as much as 50-60% for "temperate" soils. Both types of soils are found in the tropics (see Chapter 1).

Amount of pure fine limestone
needed per hectare to raise the
soil pH from:
pH 4.5 to pH 5.5 pH 5.5 to pH 6.5
Sand or loamy sand 600 kg/ha 900 kg/ha
Sandy loam 1100 kg/ha 1550 kg/ha
Loam 1700 kg/ha 2200 kg/ha
Silt loam 2700 kg/ha 3100 kg/ha
Clay loam 3350 kg/ha 4200 kg/ha

NOTE: Remember to adjust these rates for the neutralizing value and purity of the material the farmer is using.

* Based on table in Efficient Use of Fertilizers, FAO Ag Study #43.

Purity of liming materials: Unless the material has a label guarantee, it's hard to judge purity. Most developed countries have regulations that require purity and fineness guarantees for liming

materials, but not many Third World nations do. A soil lab may be able to evaluate locally available liming materials.

How to Estimate the Amount of Lime Needed

If you don't have access to a reliable soil's lab, you can roughly estimate the amount of lime needed using Table 11-3. Check the soil periodically starting about a month or two after application to measure the effect. Lime won't react much with the soil during the dry season once the topsoil dries out. If a farmer is lucky enough to be using a liming material with very fine particle size (fast-reacting), she can try test-liming a small area and having pH checked after a month or two (1000 kg/hectare of lime = 100 grams/sq. meter).

PRACTICE PROBLEM: Suppose a communal vegetable garden project needs to raise the pH of its clay loam soil from 4.5 to 5.6. The table says that about 3350 kg/ha of limestone are needed. What amount per hectare is needed if they're using burned lime estimated to be about 80% pure and the soil appears to be "tropical"?

SOLUTION: The neutralizing value of burned lime is 179%, compared to 100% for limestone so:

$\text{Kg of limestone needed} / \text{Neutralizing value of material} = \text{Amount of material needed (100\% purity)}$

$3350 \text{ kg/ha} / 1.79 = 1870 \text{ kg/ha pure burned lime needed}$

Since the burned lime is only 80% pure, a further adjustment is needed:

$1870 \text{ kg/ha} / 0.8 = 2340 \text{ kg/ha needed (234 grams/sq. meter)}$

How and when to lime

- Lime should be broadcast (spread) uniformly over the soil surface and then thoroughly mixed into the top 15-20 cm of soil (normal depth of topsoil) by plowing or hoeing. Harrowing (disking) alone will only move the material down about 5-8 cm and is inadequate.
- When broadcasting lime by hand, divide the amount in half and apply the second portion at right angles to the first. Wear a mask or bandana, and be careful if using burned or slaked lime; these are caustic materials won't burn as long as your skin is dry, but watch your eyes.
- When applying lime over established pastures, it can be spread directly over the pasture without working it in.
- Apply liming materials at least 2-6 months ahead of planting since the reaction time is slow. The caustic forms of lime are unlikely to injure the crop. Note that lime won't react during the dry season (unless the soil is irrigated), because moist soil is required.
- Where lime is expensive or difficult to apply, you can try "spot-liming" the immediate row or plant zone of the crop. Adjust the rates accordingly.
- Don't mix lime and fertilizer together since it will tie up P or release ammonia gas from N fertilizers.
- Thoroughly wash all lime from any metal application equipment to prevent corrosion.
- How often to lime: Where high rates of manure and other acid-forming fertilizers are used, liming may be needed as often as once every 2-5 years. Sandy soils and others of low buffering capacity will need reliming the most often, but they'll also require lower rates per application. Refer to Table 9-1 in Chapter 9 for more information on acid-forming fertilizers. Don't overlime!

Avoid raising the pH by more than one full unit at a time, and don't raise it much above 6.5 . It may only be necessary to raise the pH up to 5.5 to 6.0 for best yields of most crops. Overliming can be worse than not liming at all because:

- Raising the pH above 6.5 increases the likelihood of micronutrient deficiencies (except for molybdenum), especially in the case of iron and manganese.
- Phosphorus availability starts declining above a pH of 6.5, due to the formation of relatively insoluble compounds with calcium and magnesium.

Chapter 12: Salinity and alkalinity problems

Salinity and alkalinity problems are most likely to occur under 2 conditions:

- Irrigated soils in semi-arid and arid regions (less than 500 mm annual rainfall) where rainfall or irrigation isn't sufficient to leach accumulated salts out of the root zone. The salts are released by decomposing rock and other parent material below the subsoil and are also brought in by irrigation water and additions of chemical fertilizers and manure.
 - Intrusion of salt water into low-lying areas near oceans and seas.
- In humid regions, there's usually enough rainfall to flush the salts downward out of the root zone. In low-rainfall areas, irrigation may move salts downward, but they move back up again as the soil dries out between irrigations unless enough extra water is applied. The very high evaporation rates common to these drier regions aggravate this tendency. In many cases, subsurface drainage is also poor, which makes matters worse. Bringing land under irrigation may raise the

water table to within a meter or so of the surface, enabling salts to move upwards by capillary action the same way kerosene travels up a lamp wick.

Saline and alkali (sodic) soils fall into 3 classes according to the amount of soluble salts and adsorbed (held by clay and humus particles) sodium they contain: (These soils are also referred to as halomorphic soils)

- **SALINE SOILS:** These contain enough neutral soluble salts to harm plant growth much like fertilizer burn does. The salts are mainly chlorides and sulfates of sodium, calcium and magnesium. Less than 15% of the soil's exchange capacity (see Chapter 6) is occupied by adsorbed sodium ions, and the pH is usually below 8.5. Saline soils are also called white alkali soils, because the salts tend to accumulate on the soil surface. The usual causes are lack of enough water for adequate leaching, poor drainage, or both.
- **SALINE-ALKALI SOILS (Saline-Sodic Soils):** These soils not only contain excessive amount of soluble salts, but also harmful amounts of adsorbed sodium (i.e. plus-charged sodium ions that adhere to the negatively-charged clay and humus particles). More than 15% of the soil's exchange capacity is occupied by sodium ions. Although sodium is strongly basic, the pH of these soils is usually below 8.5 due to the buffering influence of the neutral soluble salts.
- **NON-SALINE ALKALI SOILS (Sodic Soils):** These soils contain only low levels of soluble salts but have excessive amounts of adsorbed sodium. More than 15% of the soil's exchange capacity is occupied by adsorbed sodium ions held by clay and humus particles. The pH is above 8.5 and often as high as 10, because there aren't enough soluble salts to exert a buffering effect. Sodic soils have very poor physical condition due to their high sodium content; it disperses and puddles (breaks down) soil aggregates (crumbs and clumps of soil particles), making the soil rather impervious to water. Sodic soils are also called black alkali soils, since their surfaces are often black due to the accumulation of dispersed humus brought to the surface by the upward capillary movement of water (from a high water table) and by evaporation.

How salinity and alkalinity harm crop growth

- **Osmotic Effect of Salts:** Soluble salts in the soil water reduce the ability of plants to absorb water through their root hair membranes (a process called osmosis). If the salt concentration is high enough, water actually starts moving out of the plant roots back into the soil, and the plant may soon die; this is called plasmolysis. At lower salt levels, plants may suffer leaf tip burn, stunting, and defoliation. Germinating seeds and young seedlings are the most sensitive to this osmotic effect. As shown in Table 12-2, crops vary considerably in their salinity tolerance.
- **Effect of Sodium:** Sodic soils harm plant growth mainly through the toxic effect of sodium itself, the high alkalinity (pH 8.5-10), and the toxicity of the bicarbonate ion with which the sodium is often associated. Germinating seeds and young seedlings are the most sensitive.
- **Boron Toxicity:** Most irrigation water contains boron which becomes toxic above 1-2 parts per million. Boron is not easily leached from the soil. Irrigation water with a high boron content may limit farming to boron tolerant crops. As shown in Table 12-3, crops vary considerably in their tolerance to boron.
- **Rainfall-induced injury:** If high evaporation and lack of sufficient leaching allow a high level of salts to accumulate at the soil surface over the weeks, an unseasonal, light rain shower may move these salts only as far as the crop root zone and cause injury. This is mainly a problem on peat soils when sub-irrigation is used. (Sub-irrigation consists of running water down wide canals through the field to raise the water table enough to irrigate plants by upward capillary movement; It's commonly used on peat soils, which tend to have high water tables.)

Lab diagnosis of salinity and alkalinity

Soil Analysis

Soil testing labs can measure the soluble salt content of soils through electrical conductivity tests. Since salts are electrolytes, the higher the salt content, the higher the electrical conductivity (EC or Ece). The readings are expressed in millimhos or micromhos. Readings can range from 0 to over 16 millimhos (16,000 micromhos).

TABLE 12-1
Soluble Salt Content of Soils and its Effect on Crop Growth

Electrical Conductivity (EC)

Millimhos Micromhos Diagnosis

Less than 2 Less than 2000 No adverse effect.

2 2000 Yields of some salt sensitive crops are affected.

Below 8 Below 8000 Crop must be moderately salt tolerant.

8-16 8000-16000 Crop must have good salt tolerance.

Above 16 Above 16000 No profitable cropping possible.

Labs can also measure the amount of adsorbed soil sodium to determine alkali danger.

Irrigation Water Analysis

The soluble salt, sodium, and boron content of irrigation water can also be analyzed.

SOLUBLE SALTS: The U.S. Salinity Lab classifies irrigation water in 4 categories according to soluble salt level:

Class 1: Low Salinity

100-250 micromhos/cm of depth (0.1-0.25 millimhos/cm). Safe to use on nearly all crops and soils. Some leaching is needed to keep salts moving downward. Salinity problems may develop on poorly drained soils.

Class 2: Medium Salinity

251-750 micromhos/cm (0.25-0.75 millimhos/cm). Can be used to irrigate relatively permeable soils. Crops need to have medium salt tolerance, and leaching will be needed.

Class 3: High Salinity

751-2250 micromhos/cm (0.75-2.25 millimhos/cm). Only for salt-tolerant crops. Adequate drainage is a must as well as ample leaching.

Class 4: Very High Salinity

Above 2250 micromhos/cm (2.25 millimhos/cm). Can't be used for irrigation except under certain conditions: permeable soil, good drainage, and high water application rates to obtain good leaching.

SODIUM IN WATER: The sodium content of irrigation water can be accurately measured, but the potential toxicity depends on the proportion of sodium in the water relative to the combined calcium and magnesium content. This is known as the Sodium Adsorption Ratio (S.A.R.) and is determined by the lab. As with soil, irrigation water can be grouped into 4 categories, ranging from Class 1 (low-sodium water) to Class 4 (high-sodium water), but the actual interpretation isn't as simple as it might appear.

Managing salinity and alkalinity problems

Reclaiming Saline Soils

Since saline soils contain only soluble salts, leaching is the cure. In many cases, however, salinity is caused by a high water table, and leaching won't be effective until artificial drainage has been installed such as underground tile drains. Deep ripping (subsoiling) may be needed to break up any hardpan that is restricting drainage.

Either periodic leaching or continuous flooding may be used. Salt-tolerant crops like beets, cotton, and barley can be grown during reclamation if flooding isn't used. The amount of water needed for leaching depends on the soluble salt content of the soil and water and the final salt level desired. As a rough guide, about 50% of the soluble salts in the root zone can be removed with 15 cm of water applied per 30 cm depth of soil (15 cm = a layer of water 15 cm deep or the equivalent of 150 liters per sq. meter). About 80% of the salts can be removed by applying 30 cm of water per 30 cm depth of soil (300 liters per sq. meter).

The leaching requirement is the ratio of the salt content of the irrigation water to that of the soil. For example where an EC of 8 can be tolerated in the root zone and the irrigation water has an EC of 8 the leaching requirement is $2/8$ or 25%. This means that 25% more water should be applied to a crop than is used up by evaporation and plant transpiration. (To help determine crop water needs, see Chapter 5 on water management).

Reclaiming Non-Saline Alkali Soils (Sodic-Soils)

Leaching alone won't remove the adsorbed sodium and insoluble sodium carbonate and bicarbonate. You need to add a soil amendment such as gypsum (calcium sulfate) first which reacts with the soil in 2 ways:

- It converts insoluble sodium salts like sodium bicarbonate into soluble sodium sulfate which is mobile and leachable.
 - It also detaches the adsorbed sodium ions adhering to the clay and humus particles and replaces them with calcium. This also results in a lowering of soil pH after leaching.
- The gypsum needs to be finely ground and should be hoed or harrowed into the surface rather than turned under with a moldboard plow. (The turning action of a moldboard ends up leaving the gypsum poorly distributed in slots.)

The soil should be kept moist to promote the reaction of the gypsum and soil. At least 5000 kg/ha (500 g/sq. meter) of gypsum is needed, but the soils lab will determine the exact amount.

On those sodic soils containing calcium carbonate (lime), sulfur can be used instead of gypsum. The soil bacteria convert it to sulfate which then reacts with the calcium carbonate in the soil to form gypsum. Much less sulfur than gypsum is needed (1000 kg of sulfur have the effect of 5380 kg of gypsum). Allow 2-3 months between sulfur application and leaching to allow the conversion to gypsum. The presence of calcium carbonate can be detected by adding several drops of sulfuric or hydrochloric acid to a small amount of soil. If fizzing occurs, this indicates calcium carbonate.

An alternative to soil amendments: Recent research by the USDA has shown that sorghum-sudangrass hybrids can be effective in freeing adsorbed sodium on sodic soils containing calcium carbonate. Sorghum-sudangrass (often called sordan) roots release unusually high amounts of carbon dioxide; the CO_2 dissolves soil calcium which can then displace the adsorbed sodium ions. Heavy irrigation is needed to flush away the freed sodium. Where suited, the use of sordan is much cheaper than gypsum and reclaims a greater depth of soil; it is also a nutritious cattle feed. However, plants less than 45 cm tall or those that have been drought-stricken or frosted contain

toxic levels of hydrocyanic acid (prussic acid).

Reclaiming Saline-Alkali Soils (Saline-Sodic Soils)

As with sodic soils, leaching alone isn't effective on saline-sodic soils, because it removes only the soluble salts, leaving behind the adsorbed sodium. Free from the buffering effect of the soluble salts, the sodium can now exert its full effect in raising the pH and deteriorating soil physical condition. In other words, leaching, by itself, converts a saline-sodic soil into a sodic soil! In a few cases, leaching without using gypsum or sulfur may be effective when the soil contains a large amount of soluble calcium or magnesium which can displace the adsorbed sodium.

Controlling the Buildup of Salinity and Alkalinity

It's seldom possible to permanently rid an affected soil of salinity and alkalinity, especially if the irrigation water is one of the causes. The best strategy is to use management practices that favor crop growth on these soils and help keep salt content at tolerable levels. Here are some guidelines:

- Treatment of irrigation water: There's no economically feasible way to reduce the soluble salt content of irrigation water, but the sodium hazard can be virtually eliminated by adding gypsum to the water. Automatic gypsum metering devices can be bought or built, or a sack of gypsum placed in the irrigation ditch.
- Use of soil amendments: Gypsum or sulfur may need to be periodically applied where conditions are favorable for the development of sodic or saline-sodic conditions.
- Crop selection: Choose crops that are tolerant to saline and alkali conditions. Boron tolerance may be an important consideration too. Tables at the end of this chapter list common crops and their tolerances.
- Improving soil drainage: Deep ripping of the soil or double-digging by hand (see Chapter 4) may be needed to break up hardpans or compacted layers to facilitate downward water movement.
- Improving soil physical condition: Organic fertilizers and soil conditioners (see Chapter 8) have an especially beneficial effect.
- Land leveling: This will smooth out depressions and rises to give more even distribution of irrigation water which will help prevent the development of pockets with high salt contents.
- Watering management: There are several watering practices that are vital in controlling salinity buildup in susceptible soils:
 - Water frequently to maintain a good soil moisture content to facilitate plant water uptake, which is hampered by the osmotic "pull" of the salts.
 - When watering, apply about 10-20% more water than needed in order to produce enough leaching for salt removal. Leaching assures that the soil salt content will never be higher than that of the irrigation water. Without leaching, soil salt content will gradually increase well above that of the water as salts accumulate instead of being flushed out.
 - Where furrow irrigation is used, increasing the water level in the furrows will aid in seed germination. Placing the seed or transplants just above the water line will help lessen salt buildup around them. (See Figure 12-1.)
 - Some sources recommend drip irrigation as a way to efficiently maintain good soil moisture and leaching of salts in the immediate plant area. Others caution that drip irrigation can produce salt buildup just as other methods do, especially at the borders between the wetted area and dry soil.

- Seedbed design: Furrow irrigation will cause salts to accumulate near the germinating seeds or the plants unless special attention is given to seedbed design. Figure 12-1 shows how bed design and irrigation techniques determine where salts accumulate and where seeds and plants should be situated.

FIGURE 12-1: Seedbed design and irrigation technique influence where salts accumulate. Single-row beds (A) with every furrow irrigated cause salt accumulation around plants. Conventional, multiple-row beds (B) or slanted, multiple-row beds (C) provide crop space in areas of lower salt concentration. Alternate furrow irrigation (D) concentrates salts in the unirrigated furrow away from crop roots.

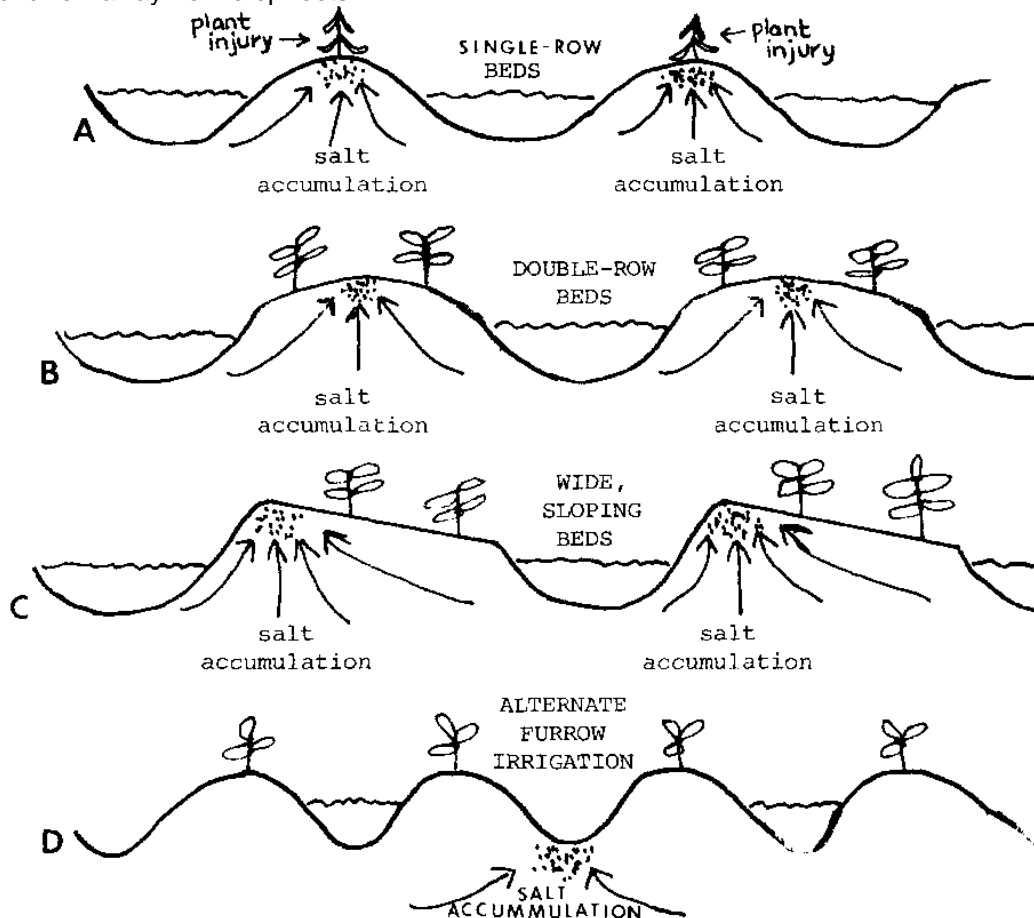


TABLE 12-2.

Relative Tolerance of Crops to Salinity*

(Listed in order of decreasing salt tolerance within each "high", "medium", and "low" grouping)

FRUIT CROPS

High Medium Low

Date palm Pomegranate Pear

Coconut Fig Apple

Olive Orange

Grape Grapefruit

Peach

Strawberry

Lemon

Avocado

VEGETABLES

High Medium Low

Beets** Tomatoes Radish

Kale Broccoli Celery

Spinach Cabbage Beans

Bell pepper

Cauliflower

Lettuce

Sweet corn

Potatoes

Carrots

Onions

Peas, garden or field

Squash

Cucumber

Cantaloupe

FIELD CROPS

High Medium Low

Barley Rye Beans

Sugar beets** Wheat

Cotton Oats

Rice

Sorghum

Maize

Sunflower

* From "Principles and Practices in the Irrigation of Texas Soils", Texas Agric. Expt. Station Bull.

** Beets and sugar beets are sensitive to salinity during seed germination.

TABLE 12-3.

Relative Tolerance of Some Crops to Boron

(Listed in order of decreasing tolerance to boron within each group)

Tolerant	Semi-tolerant	Sensitive
Date palm	Sunflower	Pecan
Coconut palm	Acala cotton	Navy beans
Sugar beet	Potato	Plum
Garden beet	Pima cotton	Pear
Alfalfa	Tomato	Apple
Onions	Sweet pea	Grape
Turnip	Radish	Kardota fig
Cabbage	Field pea	Persimmon
Lettuce	Barley	Peach
Carrot	Wheat	Orange
Maize	Avocado	
Grain sorghum	Grapefruit	
Oats	Lemon	
Pumpkin		
Bell pepper		
Sweet potato		
Lima bean		

Appendixes

Appendix A: Useful measurements and conversions

AREA

1 SQ. METER = 10.76 sq. ft.

1 HECTARE (ha) = 10,000 sq. meters = 2.47 acres = 1.43 manzanas (parts of Latin America)

1 ARE (a) = 100 sq. meters = 0.01 hectares

1 ACRE = 4000 sq. meters = 4840 sq. yards = 43,560 sq. ft. = 0.4 hectares = 0.58 manzanas

(parts of Latin America)

1 MANZANA (used in parts of Latin America) = 10,000 sq. varas = 7000 sq. meters = 0.7 hectares = 1.73 acres

LENGTH

1 METER (m) = 100 cm = 1000 mm = 39.37" = 3.28 ft.

1 CENTIMETER (cm) = 10 mm = 0.01 m = 0.4"

1 MILLIMETER (mm) = 0.001 meter = 0.04"

1 KILOMETER (km) = 1000 m = 0.625 miles

1 VARA (Latin America) = 83.7 cm = 32.8"

1 MILE = 1.6 km = 1600 meters = 5280 ft.

WEIGHT

1 KILOGRAM (kg) = 1000 grams (g) = 2.2 lbs. = 35.2 oz.
1 POUND (lb.) = 16 oz. = 454 g = 0.454 kg 1 OUNCE (oz.) = 28.4 g
1 METRIC TON = 1000 kg = 2202 lbs.
1 LONG TON = 2240 lbs. 1 SHORT TON = 2000 lbs.
1 QUINTAL = 100 kg (metric system), 100 lbs. (Latin America)

VOLUME

1 LITER (l) = 1000 cc = 1000 ml = 1.06 U.S. quarts
1 HECTOLITER (hl) = 100 liters
1 CUBIC METER = 1000 liters
1 CUBIC FOOT = 7.48 U.S. gallons = 28.3 liters
1 GALLON (U.S.) = 3.78 liters = 3780 cc (ml)
1 GALLON (Imperial) = 5 U.S. quarts = 4 Imperial quarts = 4.725 liters
1 ACRE-INCH (of water) = 26,928 U.S. gallons
1 BUSHEL (U.S., English) = 1.25 cubic ft. = 9.375 U.S. gallons = 35.4 liters = 66 lbs. shelled, dry
maize or sorghum = 60 lbs. dry wheat kernels or beans

1 FLUID OUNCE (fl. oz.) = 30 cc (ml) = 2 level tablespoons (measuring type)

1 TABLESPOON (measuring type) = 15 cc (ml) for solids or 18 cc (ml) for liquids, due to surface tension.

1 TEASPOON (measuring type) = 5 cc (ml) for solids or 6 cc (ml) for liquids, due to surface tension.

MISCELLANEOUS CONVERSIONS

lbs./acre X 1.12 = kg/ha; lbs./acre X 1.73 = lbs./manzana

kg/ha X 0.89 = lbs./acre; kg/ha X 1.54 = lbs./manzana

lbs./manzana X 0.58 = lbs./acre; lbs./manzana X 0.65 = kg/ha

1 LITER PER SQ. METER = a 1 millimeter thickness (layer)

7 U.S. GALLONS PER SQ. METER = a 1 inch thickness (layer)

Temperature:

$$C^{\circ} = (F^{\circ} - 32^{\circ}) \times 0.55$$

$$F^{\circ} = (C^{\circ} \times 1.8) + 32^{\circ}$$

Appendix B: How to determine soil moisture content
DETERMINING SOIL MOISTURE BY FEEL OR APPEARANCE *1
Feel or Appearance of Soil

Available

Moisture in Soil

VERY COARSE

TEXTURE (Sand)

COARSE TEXTURE

(loamy sand or

sandy loam)

MEDIUM TEXTURE

(Fine sandy loam,

silt loam)

FINE TEXTURE

(clay loam or clay)

0% Dry, loose, and single grained; flows through fingers.

Dry and loose; flows through fingers.

Powdery dry; sometimes slightly crusted but breaks easily into powder.

Hard, baked, cracked, often with crumbs on surface.

50% or less Appears dry; won't form a ball under pressure. *2

Appears dry; won't form a ball under pressure.

Somewhat crumbly but holds together under pressure.

Somewhat pliable; balls under pressure.

50-75% Appears dry; won't form a ball under pressure.

Tends to ball under pressure but seldom holds together.

Forms a ball under pressure; will sometimes stick slightly with pressure.

Forms a ball; ribbons out between thumb & forefinger.

75% to field capacity (100%)

Sticks together slightly; may form very weak ball under pressure.

Forms weak ball, breaks easily, will not slick.

Forms ball; very pliable, slicks readily if high in clay.

Easily ribbons out between fingers; has a slick feel.

At field capacity On squeezing, no free Same as for sand. Same as for sand. Same as for sand. (100%) water appears on soil but wet outline of ball

left on hand.

*1. Based on USDA Ag. Info. Bul. No. 199.

*2. Ball is formed by squeezing a handful of soil very firmly.

Appendix C: Spacing guide for contour ditches and other erosion barriers*

(See Chapter 3)

% SLOPE DEGREES SLOPE DISTANCE BETWEEN DITCHES** IN METERS

5	3°	21.6
6		19.3
7	4°	17.7
8		16.6
9	5°	15.8
10		15.0
11	6°	14.2
12	7°	13.4
13		12.7
14	8°	12.1
15		11.5
16	9°	11.0
17		10.5
18	10°	10.0
19		9.5
20	11°	9.0
21		8.6
22		8.2
23		7.8
24		7.5
25	14°	7.2
26		7.0
27		6.7
28		6.4
29		6.2
30	17°	6.0
31		5.8

32 5.6
 33 5.4
 34 5.2
 35 19° 6.0
 36 4.9
 37 4.8
 38 4.7
 39 4.6
 40 22° 4.5
 41 4.4
 42 4.3
 43 4.3
 44 4.1
 45 24° 4.0

* These spacings are suitable for contour ditches, rock walls, and other erosion barriers.

** The distances in column 3 are based on Peace Corps project experience in El Salvador.

Check with conservation specialists in your region for their recommendations.

Appendix D: Composition of common chemical fertilizers

NITROGEN SOURCES N% P₂O₅%* K₂O%* S%*

Ammonium nitrate 33.5-34 0 0 0
 Ammonium nitrate with lime 20.6 0 0 0
 Ammonium nitrate-sulfate 30 0 0 6.5
 Ammonium sulfate 20-21 0 0 23-24
 Ammonium phosphate sulfate (2 kinds) 16 20 0 9-15
 13 39 0 7
 Mono-ammonium phosphate (2 kinds) 11 48 0 3-4
 12 61 0 0
 Di-ammonium phosphate (3 kinds) 16 48 0 0
 18 46 0 0
 21 53 0 0
 Calcium nitrate 15.5 0 0 0
 Sodium nitrate 16 0 0 0
 Potassium nitrate 13 0 46 0
 Urea 45-46 0 0 0

PHOSPHORUS SOURCES

Single superphosphate 0 16-21 0 8-12
 Triplesuperphosphate 0 42-47 0 1-3
 Mono- & all-ammonium phosphates (see under nitrogen)
 Ammonium phosphate sulfate (see under nitrogen)

POTASSIUM SOURCES

Potassium chloride (muriate of potash) 0 0 60-62 0
 Potassium sulfate 0 0 50-53 18
 Potassium nitrate 13 0 44-46 0
 Potassium magnesium sulfate (11% Mg, 18% MgO) 0 0 21-22 18

* $P_2O_5 \times 0.44 = P$; $K_2O \times 0.83 = K$; $S \times 3.0 = SO_4$

Appendix E: Hunger signs in common crops

NOTE: Before trying to diagnose hunger signs, read over the section in Chapter 7 on their usefulness and drawbacks.

NITROGEN DEFICIENCY

Cereal Grains (Maize, Sorghum, Millet, Rice, Wheat): Young plants are stunted and spindly with yellowish-green leaves. In older plants, the tips of the lower leaves show yellowing first which progresses up the mid-rib in a “V” shaped pattern, the leaf margins remaining green. In some cases, there's a general yellowing of the lower leaves. In severe N hunger, the lower leaves eventually turn brown and die, starting at the tips. This “firing” can also be caused by drought which prevents N uptake. Maize ears are pinched at the tips.

Pulses and Pasture Legumes (Peanuts, Beans, Kudzu, etc.)

Many legumes like peanuts, cowpeas, mung beans, soybeans, and pasture legumes can fix all the N they need if the right strain of rhizobia bacteria is present. Others, such as beans, garden peas, and non-vining lima beans, are less efficient.

N-deficient legumes have pale green leaves with a yellowish tinge, starting first with the lower leaves. In severe cases, leaf drop may occur.

If an efficient N fixer like peanuts or soybeans shows N deficiency symptoms, check for adequate nodulation (refer to the section on pulses in Chapter 10).

Vegetables

Tomatoes first show stunted growth and loss of normal green color, first in the younger, upper leaves which stay small and thin. The whole plant gradually becomes light green to pale yellow. The veins begin to change from light green to purple, especially on the underside of the leaves. Stems may turn purple. Flower buds may turn yellow and drop off, and fruits are small.

Cucumbers and squash first show leaf stunting and a loss of deep green color. Stems are spindly, and fruits are light in color (cucumbers).

Potatoes have light green to yellowish-green leaves. In late stages, leaf margins turn yellow and tend to curl.

Other vegetables show a general leaf yellowing.

PHOSPHORUS DEFICIENCY

Cereal Grains

P hunger signs are most likely to occur during early growth. Mild shortages usually cause stunting without clear leaf symptoms. More severe shortages cause a purplish color starting at the tips of the lower (older) leaves which may even turn brown and die. Some varieties of maize and sorghum don't show a purplish color but rather a bronze coloration of the same pattern. Disregard purple stems.

In maize, a purplish color can be caused by either low temperatures or P shortage. Low temperatures make it more difficult for the roots to absorb P; however, the purpling can be caused by low temperature alone even when the plains level of P is adequate.

In maize and sorghum, symptoms usually disappear once the plants reach 40-45 cm, but yields will be severely lowered. Maize ears from P deficient plants are somewhat twisted, have irregular

seed rows, and seedless tips.

Pulses and Pasture Legumes: Hunger signs often aren't well defined. Plants lack vigor and have few side branches. Upper leaves become dark green but remain small. Flowering and maturation are retarded.

Vegetables

Leaves of most vegies first fade to a lighter color. In tomato and Crucifer Family plants (cabbage, turnip, etc.), a purple color develops on the undersides of the leaves or along the veins. (On tomatoes, this can be confused with deficiency).

Potatoes have smaller than normal leaves with a darker color than usual; leaves fail to expand normally. Tubers may have rusty brown lesions in the flesh.

POTASSIUM DEFICIENCY

Cereal Grains: Maize, sorghum, and millet, etc. rarely show symptoms the first several weeks of growth. The margins of the lower leaves turn yellow and die, starting at the tip. K-deficient plants have short internodes (distance between the nodes) and weak stalks. Maize stalks sliced lengthwise often reveal nodes that are discolored and a darkish brown. Maize ears from K-deficient plants are often small and may have pointed, poorly seeded tips.

Pulses and Pasture Legumes: K deficiency is fairly easy to spot. In broad-leaved legumes like beans and cowpeas, early signs are irregular yellow mottling around the leaflet edges, especially in the lower part of the plant. This turns into a "firing" of the leaf margins that may move inward to cover half the leaf.

Vegetables

Tomatoes will grow slowly and have a dark blue-green color. The young leaves become crinkled; older leaves turn dark green and then develop a yellow-green color around the margins. Blotchy ripening of tomatoes can be caused by K deficiency.

Cabbage plants first show bronzing of the leaf edges which then turn brown and dry out.

Potatoes: The early appearance of unusually dark green, bluish-green, or glossy foliage is a dependable sign. Older leaves become yellowish and develop a brown or bronze color starting at the tips. A number of lower leaves may dry up at the same time. Plants become stunted and seem to droop due to downward curling of the leaves. Tuber flesh turns dark when cooked.

CALCIUM DEFICIENCY

Calcium deficiencies are very unlikely except in some vegetables and peanuts.

Maize leaf tips become stuck to the next lower leaf.

Beans: Ca hunger is most likely to occur in combination with aluminum toxicity on very acid soils. Leaves stay green with a slight yellowing at the margins and tips. Leaves may pucker and curl downward.

Peanuts: Light green plants with a high percentage of "pops" (unfilled pods).

Tomatoes: Blossom end rot is caused by calcium deficiency which is promoted by "feast-or-famine" watering and severe pruning. The blossom end (bottom end) of the fruit becomes sunken and dark, eventually rotting.

Celery will develop brown, decaying areas in its heart leaves.

Carrot roots will have cavity spots.

MAGNESIUM DEFICIENCY

Where to suspect deficiencies: Very acid soils or soils that have been limed with a material low in magnesium. High K applications encourage deficiencies.

Cereal Grains: A general yellowing of the lower leaves is the first sign. Eventually, the areas between the veins turn light yellow to almost white, while the veins remain fairly green. As the deficiency progresses, the leaves turn reddish-purple along their edges and tips, starting at the lower leaves and working upwards.

Pulses: Interveinal (between the veins) yellowing appears first on the older leaves and then moves upwards. Leaf tips show the first effects.

Vegetables: Cabbage, cucumber, watermelon, tomato, eggplant, and pepper are the most susceptible. Tomatoes get brittle leaves which may curl upwards (caused by other things too). The veins may stay dark green while the areas between turn yellow and finally brown.

SULFUR DEFICIENCY

Where to suspect: Volcanic soils; acid, sandy soils; where low-S fertilizers have been used exclusively for some time.

Cereal Grains: Cereals have relatively low S needs. Stunted growth, delayed maturity, and a general yellowing of the leaves (as distinguished from N hunger) are the main signs. Sometimes the veins may stay green which can be mistaken for iron or zinc deficiency; however, iron and zinc hunger are more likely in basic or only slightly acid soils.

Other Crops: Signs aren't easily recognizable in most crops. In beans, the upper leaves turn uniformly yellow.

ZINC DEFICIENCY

Where to suspect: Soil pH above 6.8; where high rates of P have been applied, especially if locally placed near the row. Maize is very sensitive to Zn deficiency.

Cereals: Maize shows the most clearly recognizable zinc hunger signs of any crop. If severe, symptoms appear within 2 weeks of emergence. A broad band of bleached tissue on each side of the mid-ribs of the upper leaves, mainly on the lower part of the leaves, is typical. Mild shortages may cause an interveinal striping similar to manganese and iron hunger. However, in the case of Fe and Mn shortages, the interveinal striping runs the full length of the leaf. Sorghum shows similar signs but with less interveinal striping, and the white band is more defined.

Pulses and Pasture Legumes: Interveinal yellowing of the upper leaves.

IRON DEFICIENCY

Where to suspect: Soil pH above 6.8; sorghum and legumes.

Cereal Grains: Sorghum is much more prone to iron deficiency than maize. Cereals show an interveinal yellowing that extends the full length of the leaf and occurs mainly on the upper leaves.

Pulses: Interveinal yellowing of the upper leaves which eventually turn uniformly yellow.

MANGANESE DEFICIENCY

Where to suspect: Soil pH above 6.8; sandy or highly leached soils.

Cereal Grains: Very uncommon.

Peanuts: Yellowing between the veins of the upper leaves which eventually become uniformly yellow and then bronzed.

Beans: Plants are stunted, and upper leaves become yellow between the small veins and eventually take on a bronzed appearance.

Manganese toxicity occurs on very acid soils and is accentuated by poor drainage. Beans are very susceptible. Upper leaves show an interveinal yellowing which is easily confused with Zn or Mg deficiency, but Zn hunger is very unlikely under acid conditions.

BORON DEFICIENCY

Where to suspect: Acid, sandy soils or high pH soils. Boron is the most common micronutrient deficiency on most vegetables. Cereals rarely show B deficiency.

Peanuts: Foliage may be normal but seeds often have a hollowed out, brownish area in the meat, usually referred to as “internal damage”.

Beans: Thick stems and leaves with yellow and dead spots; if less severe, leaves are puckered and curl downward; easily confused with leafhopper damage and virus attack.

Table beets, turnips, and root crops show dark spots on the root, usually at the thickest part; this is known as “brown heart”. Plants are stunted with smaller than normal leaves which develop yellow and purple-red blotches. Leaf stalks show a lengthwise splitting. The growing point may die.

Sweet potatoes: Plants are stunted with short internodes and curled petioles (the leaf stems). The edible roots have surface cankers covered with a black exudate.

Lettuce shows malformation of the quicker growing leaves, death of the growing point, and leaf tip burning and spotting.

MOLYBDENUM

Where to suspect: Acid soils. Legumes, Crucifer family (cabbage, cauliflower, etc.).

Pulses, Pasture Legumes: Since Mo is needed by the rhizobia bacteria, Mo-deficient legumes often show signs of N hunger.

Cabbage, Cauliflower, Broccoli, etc.: Interveinal yellowing along with cupping of the leaf margins. Leaves have a whiplike appearance.

COPPER: Copper deficiency is very uncommon but is most likely to occur in peat soils. Tree fruits and pasture legumes (especially stylo) are the most susceptible. Symptoms are varied but partial dying back of terminal shoots in fruit trees is one sign.

Appendix F: Legumes for green manuring and cover-cropping in tropical and subtropical regions

NOTE:

- For additional information, refer to the section on green manures and cover crops in Chapter 10.

- Seed inoculation and cross-inoculation groups: See the section on pulses in Chapter 10 and Table 10-3.

- Before using these species, check first with your country's extension service and experiment stations concerning their experience with them.

Seed scarification: The seeds of some tropical legumes such as centrosema, tropical kudzu, and leucaena have hard, impermeable seed coats which must be broken (scarified) to allow moisture absorption for germination. Several methods can be used:

- Hot water treatment: Soaking for 2-3 minutes at 80°C (176°F) or for 3 seconds in boiling water. Higher temperatures or longer immersions will damage the seed. If such accuracy isn't possible, bring water to a boil, allow to cool for 30 seconds, and then pour it over the seeds, allowing them to soak overnight before planting. Expect in the case of overnight soaking, the heat-treated seeds can be stored for several months or more if quickly air-dried.

- Mechanical means: Seed can be rubbed between sandpaper boards or placed in a drum lined with sandpaper and stirred or rotated to abrade the seed. Leucaena seeds can be nicked with toenail clippers.

I. Quick-Growing Legumes for Short-Term Use (40-90 days)

Glycine max (Soybeans): Annual bush or vining pulse crop requiring 130-160 days for seed production. Moisture needs similar to those of maize. Prefer a soil pH of 6.0-7.0. Varieties are highly daylength-sensitive and must be suited to the local photoperiod. Most varieties are susceptible to nematodes. Prone to diseases when grown in humid conditions. Require a very specific type of rhizobia bacteria.

Phaseolus aureus (Mungbean, Green Gram, Golden Gram): Widely grown in S.E. Asia as a pulse crop; adapted as a short-term green manure/cover crop. Stem-rot resistant but susceptible to nematodes and poor drainage. Fair drought tolerance.

Pueraria acutifolius (Tepary Bean): Annual bushy or viny plant well adapted to hot-dry areas with less than 500 mm annual rainfall and in frequent but heavy rains. Needs good moisture from germination to flowering but can often mature its seed without additional rain. Native to Mexico and Southwest U.S. Only moderately tolerant of salinity and alkalinity, but needs good drainage. Not adapted to humid, high-rainfall conditions. Very resistant to common bean blight (a bacterial disease; Xanthomonas phaseoli). Mature seeds are produced in 60-90 days after plant emergence. Dry seeds are edible after soaking and boiling; references disagree as to flavor ("strong-tasting", "mild-flavored"). Leaves and pods can be fed to livestock.

Sesbania macrocarpa (Syn. S. exaltata) [Coffeeweed]: Quick-growing, erect annual suitable as a green manure. Susceptible to nematodes. Can become invasive if allowed to set seed.

Vigna unguiculata (Syn. V. sinensis) [Cowpea]: Grown for edible seeds and young pods, forage, green manuring, and cover cropping. Varieties range in growth habit from bushy determinates (seed produced over a short period) to viny indeterminates (seed produced over several months). Best adapted to 400-1500 mm annual rainfall. Well adapted to semiarid regions. Better tolerance to heat, drought, and soil acidity than common beans (Phaseolus vulgaris). Poor tolerance of soil salinity. Requires good drainage. Some varieties have good root knot nematode resistance. Makes good hay. Seed matures 60-200 days after planting with bush types being the earliest. V. sesquipedalis (yardlong bean, asparagus bean) is a closely related species widely grown in Asia. Nodulates readily.

II. Bush or Viny Legumes Suited for Long-Term Use (90 days +)

Calopogonium mucunoides (Calopo): Short-lived, vigorous, climbing perennial suited to hot, humid tropical areas with rainfall over 1500 mm. Not very palatable to livestock but may be eaten during dry season.

Clitoria ternatea (Butterfly Pea): Very drought tolerant; small leaved and doesn't cover the ground well. Grows in Central America at sea level.

Canavalia ensiformis (Jack Bean): A bushy, semi-erect annual 60-120 cm tall; can become a perennial climber; adapted to annual rainfall as low as 650-750 mm; fairly drought tolerant once established; tolerant of acid soils; withstands some waterlogging. Forage palatable to livestock only when dried and needs gradual introduction. Young leaves and pods can be eaten after cooking. The dried seeds are unattractive in flavor and must be soaked and boiled in salted water for several hours to soften them and remove toxins; they can also be detoxified by fermenting into tempeh. Produces green, immature pods in 90-120 days after sowing and mature seeds in 180-300 days.

Canavalia gladiata (Sword Bean): Vigorous perennial climber reaching 4-10 m in length; can be treated as an annual. Grows best under 900-1500 mm annual rainfall; once established, it has some drought tolerance. Most varieties have only poor to fair tolerance of waterlogging. Tolerant of acid soils. Forage palatable to livestock only when dried. Immature green pods widely used as green beans in Asia; mature seeds contain toxins which require soaking and boiling to remove and have a strong flavor and thick, tough seedcoat.

Centrosema pubescens (Centrosema, Centro): Aggressive vining perennial that readily climbs. Best for areas having over 1000 mm rainfall. Tolerant of acid soils and has some tolerance of poor drainage. Moderately palatable to livestock. Seed inoculation recommended as its rhizobia bacteria is somewhat strain-specific. If seeding conditions are secure, the seeds should be scarified with hot water to assure uniform germination. Some varieties can be propagated by stem cuttings. Withstands fairly heavy grazing.

Crotalaria spp.: Most species are erect annual or perennial shrubs reaching 90-180 cm. Green forage, hay, and silage of *C. juncea* (sunn hemp) and *C. spectabilis* (showy crotalaria, rattlebox) are toxic to livestock; seeds of all types are toxic. Best adapted to sandy soils and well-drained areas.

Desmodium intortum (Greenleaf Desmodium): Vining perennial best adapted to 900-1500 mm rainfall. Tolerant of acidic soils and waterlogging. Very palatable to livestock. Best as a grazed cover crop. Established by seed or stem cuttings.

Desmodium uncinatum (Silverleaf Desmodium): Lower tolerance to drought and waterlogging than greenleaf but withstands light frosts. Excellent forage. Best as a grazed cover crop.

Dolichos lablab (Lablab Bean, Hyacinth bean): Vigorous annual or biennial vining plants that make good forage. Flowers, leaves, and dried seeds are edible for humans. Adapted to areas with 500-2500 mm rainfall; needs good moisture for establishment. Good tolerance to acid soils and to aluminum toxicity, but needs good drainage. Grows well wherever cowpeas do but has better disease and insect resistance, though it is susceptible to nematodes. Seeds mature in 150-200 days and are unusually large, making them ideal for rough seedbed conditions. Competes well with weeds during establishment. Seeds mature 150-200 days after sowing. Withstands rotational grazing but cattle require time to adapt to it.

Indigofera hirsute (Hairy indigo): Annual shrub growing to 1.2-2 m. Adapted to acid, sandy soils. Makes good hay if cut before 90 cm. Has suppressant effect on root knot nematodes. Nodulates readily with cowpea rhizobia group.

Phaseolus atropurpureus (Siratro): Deep-rooted perennial used mainly for pasture. Best adapted to 750-2000 mm rainfall but has good drought tolerance. Requires good drainage. Resistant to nematodes. Reacts to stress by shedding its leaves. Easily established by seed; stem cuttings

can also be used. Nodulates readily with cowpea rhizobia. Susceptible to *Rhizoctonia* stem rot in high rainfall regions.

Phaseolus lathyroides (Phasey bean): Self-regenerating (by seed fall) annual or biennial erect plants eventually developing vines. Best adapted to subtropical areas with over 750 mm rainfall. Fair tolerance to waterlogging but susceptible to nematodes. Tolerant of acid, infertile soils. Forage is palatable to livestock. Nodulates readily with cowpea rhizobia.

Phaseolus lunatus (Lima bean): There are 2 groups of lima beans: bushy-erect and tropical vining. Unlike the bushy-erect types, the tropical vining types are especially well adapted to hot-humid conditions and are often the principal pulse crop of the wet rainforest regions of Africa and Latin America; unlike the bushy types, the vining types are efficient nitrogen fixers. However, they are susceptible to nematodes, have poor drought tolerance, and don't do well below a soil pH of

6.0. Seeds, immature pods, and leaves are eaten, but some varieties (especially those with dark-colored seeds) have toxic levels of hydrocyanic acid in these parts which must be removed by boiling and changing the cooking water.

Pueraria phaseoloides (Tropical Kudzu, Puero): Vigorous vining perennial with stems up to 8 m long. Best adapted to ample rainfall (over 1500 mm). Tolerant of acid soils and somewhat tolerant of poor drainage. Very palatable to livestock and withstands moderate grazing. Fair drought tolerance. Established by seed which should be soaked for 24 hours or treated with hot water. Stem cuttings can also be used. Not to be confused with common (Japanese) kudzu, which is a much more aggressive subtropical species.

Stizolobium spp. (Syn. *Mucuna pruriens*) [Velvet Bean]: A vigorous annual or perennial climbing vine for forage and green manuring/cover cropping. Best adapted to 1200-1500+ mm of rainfall; not as drought tolerant as *C. ensiformis*. Grows from sea level to 2000 m in the tropics. Well adapted to sandy, less fertile soils. Fair tolerance of soil acidity but require good drainage. Seed produced in 180-270 days, although the few early-maturing varieties require just 110-130 days. Seeds are unusable for poultry but can be fed up to the 25% level to pigs. Seeds eaten by humans but require soaking and boiling to remove a toxin. Toasted, ground seeds used as a coffee substitute. Some varieties have an irritating, itchy powder on the pods. Relatively free from insect attack but susceptible to some species of root knot nematode. Nodulates with cowpea rhizobia.

Stylosanthes guyanensis (Stylo): A perennial erect small shrub growing up to 1.5 m. Best adapted to rainfall above 900 mm. Very tolerant of low fertility and acid soils but responds well to added P where lacking; sensitive to copper deficiency. Some tolerance of poor drainage. Good livestock forage but less resistant to heavy grazing than centro or siratro. Palatability varies but improves as growth progresses. Not very drought resistant but can re-establish itself through self-sown seed. Established by seed which needs scarification. All varieties except Schofield require a specific strain of rhizobia bacteria.

Stylosanthes humilis (Townsville Stylo): A self-regenerating (through reseeding) annual or biennial erect shrub whose branches can reach 90 cm in length. Needs at least 600 mm annual rainfall. Well adapted to low fertility and acid soils and is a good P extractor. Needs good drainage. Palatable to livestock and makes good hay. Withstands grazing well.

III. Legume Trees and Shrubs Suited for Cut-and-Carry Green Manuring

DANGER: Some of the species below, such as *Sesbania bispinosa*, are aggressive and quick-growing; they may become invasive. Use native species of known behavior whenever possible.

Cajanus cajan (Pigeon pea): Short-lived perennial shrub often grown as annual since seed yield declines after the first year. Used for cut-and-carry green manuring, soil improvement, forage, firewood, and for its edible seeds and young pods. Deep rooted and drought tolerant. Best

adapted to annual rainfall of 600-1000 mm. Requires good drainage. Some tolerance to salinity. Mature seed produced 100-250 days after sowing. Can be cropped for 2-3 years, but yields

decline quickly after that. Can be maintained up to 5 years as a forage or green manure crop. Some varieties susceptible to root knot nematodes. Readily nodulates with cowpea rhizobia.

Calliandra calothyrsus (Calliandra): A small tree (up to 10 m tall) used for firewood, erosion control, windbreaks, cut-and-carry green manuring, and beautification. Reaches 2.5-3.5 m in 6-9 months. Best adapted to rainfall over 1000 mm but withstands several months of drought. Some tolerance of poor drainage. Competes well with weeds. Coppices (regrows) readily after cutting. Established by seed or large cuttings. Nodulates freely with cowpea rhizobia. Seed needs hot water treatment.

Gliricidia sepium (Madre de Cacao, Quickstick, Madera Negra): A quick-growing tree for timber, live fencing, shade, forage, cut-and-carry green manuring, and honey foraging. Best adapted to rainfalls of 1500-2300 mm. Leaves are palatable to cattle but poisonous to most other animals. Roots, bark, and seeds are toxic; leaves can be toxic to humans. Leaves drop during dry season. Coppices (regrows) readily after cutting; can be trimmed every 1-2 months. Established by seed or large cuttings which readily root.

Leucaena leucocephala (Leucaena, Ipil-Ipil): Multi-purpose, deep-rooted shrub or tree suitable for cut-and-carry green manuring. Best adapted to areas below 500 m elevation with 500-2000 mm rainfall. Needs good drainage and a soil pH of 5.0 or above. Can be seriously attacked by psyllid insects (jumping plant lice). Makes slow initial growth and is easily wiped out by weeds, termites, ants, and rodents. Growth becomes very rapid after the first few weeks and can reach 4-6 m in 12 months. Quickly regrows new foliage within 2-3 weeks. Its high-protein leaf forage contains mimosine which is toxic to non-ruminants unless fed at low levels. Some low-mimosine leucaena varieties have been identified. Inoculation with leucaena-specific rhizobia is sometimes recommended. However, the Nat. Academy of Sciences states that seed inoculation isn't normally needed even when leucaena is planted on new ground, especially if other leguminous trees like Calliandra, Gliricidia, Sesbania, and Mimosa are present; however, specific rhizobia strains for Leucaena are now available. Seed scarification is needed for good germination, due to the hard seed coat. Other uses: firewood, edible seeds, poles, reforestation, living fence. Can become an aggressive weed.

Mimosa scabrella: Rapid-growing thornless tree used for firewood, beautification, live fencing, and cut-and-carry green manure. Can reach 5 m height in 14 months. Native to the cool subtropical savanna of S.E. Brazil but can grow in warmer areas; stunted by wet soils. Good nitrogen fixer.

Sesbania bispinosa (Prickly Sesban): Quick-growing shrub up to 4 m tall that can produce firewood in 6 months. Good drought tolerance but does best at 550-1100 mm rainfall and up to 1200 m elevation. Good tolerance of saline and alkaline soils. Tolerates wet soils but not long periods of waterlogging. Palatable to cattle. Suitable for cut-and-carry green manuring. Can become an invasive weed due to its abundant seed production. Freely nodulates with cowpea rhizobia.

Sesbania grandiflora (Agati, Katurai, West Indian Pea Tree): Small, fast-growing tree up to 10 m tall. Used for firewood, reforestation, forage, food, and cut-and-carry green manure. Best adapted to rainfall over 1000 mm and elevations below 800 m. Adapted to wide range of soils; some tolerance to waterlogging. Very susceptible to nematodes. Young leaves, young pods, and giant flowers are popular vegetables in Asia. Established by seed. Freely nodulates with cowpea rhizobia group.

Sesbania sesban (Sesban): Fast-growing, short-lived shrub 4.5-6 m tall used for wood, forage, food, and green manure. Requires 350-1000 mm rainfall. Tolerates acid soils, saline soils, and periodic waterlogging. Forage is very palatable. Regrows readily after cutting. Flowers, leaves, and seeds are edible for humans; seeds require soaking and cooking to remove a toxin. Widely used in the tropics as a green manure for rice and should be turned under at least 3 weeks before

transplanting. In double-crop rice areas, it can be interplanted at a late stage of the first crop and then used as a green manure for the second crop.

Appendix G: Some sources of technical support

- The International Agricultural Research Institutes
- Private and Voluntary Organizations (PVO's)

I. THE INTERNATIONAL AGRICULTURAL RESEARCH INSTITUTES

In the early 1960's, the growing realities of the world food problem helped stimulate worldwide interest in the agricultural and nutritional dilemma faced by the developing countries. There are now some 9 major international research institutes dealing with food crops in developing countries and 2 dealing mainly with livestock. Most of them were initially sponsored by international foundations like Ford, Rockefeller, and Kellogg. However, in 1971 the Consultative Group for International Agricultural Research (CGIAR) was formed to provide broad-based financial support for the institutes. The CGIAR is jointly sponsored by the Food and Agric. Org. (FAO), the International Bank for Reconstruction and Development (IBRD), and the United Nations Development Program (UNDP).

Role of the International Institutes

- To undertake multidisciplinary, field-oriented research for developing yield-increasing technologies.
 - To cooperate with appropriate national crop and livestock improvement programs in the developing countries; this includes training programs, providing new varieties for field testing, and supplying professional personnel.
 - To collect and preserve crop and livestock genetic material vital for the development of improved varieties and stock.
 - To provide training programs for agricultural personnel from developing countries.
- Due to the many variations in soils, climate, and pests, etc., the development of suitable improved technologies is a very location-specific endeavor that requires adaptive research on a region-by-region basis within each country. Unfortunately, such country-sponsored efforts tend to be the weak link in the system, because they are often underfinanced and understaffed.

How to Utilize the International Institutes

Some suggestions:

- Your first contact should be to request the institute's brochure describing its activities. Also request a catalog of their publications. These institutes are one of the best sources of up-to-date research and production information. Some excellent troubleshooting guides are available for specific crops like maize (CIMMYT), millet/sorghum (ICRISAT), rice (IRRI), and beans/cassava (CIAT). (Some of these are available through PC/ICE; refer to Appendix H.)
- The institutes are not set up to respond to general queries regarding appropriate production information for your specific area. They operate with a limited staff.
- Check with your Ministry of Agriculture to see what cooperative research efforts are being conducted in your country with the help of the international institutes.
- Most of the institutes offer short and long-term training courses which might be of great value to research and extension personnel in your area. Perhaps you could help a host country extension worker or technician obtain a scholarship or government grant for such training.

Major International Research Institutes

Funded by CGIAR

CIAT: The International Center for Tropical Agriculture focuses on beans, cassava, maize, rice, and tropical pastures. Address: Apartado Aereo 6713, Cali, COLOMBIA, S.A.

CIMMYT: The International Maize and Wheat Improvement Center Address: Londres 40, Apdo. Postal 6-641, Mexico, D.F.

CIP: The International Potato Center is conducting innovative research in potato breeding, storage, alternative propagation practices (i.e. other than using seed pieces), warm weather adaptation, and other areas. Address: CIP, Apartado 5969, Lima, PERU, S.A.

ICARDA: The International Center for Agric. Research in Dry Areas focuses on chickpeas, pigeonpeas, and other arid land crops. Address: P.O. Box 5466, Aleppo, SYRIA.

ICRISAT: The International Crops Research Institute for the Semi-arid Tropics, focuses on millet, sorghum, peanuts, chickpeas, and pigeonpeas. It has recently established a Sahelian center in Niger, West Africa for work on millet and peanuts. Address: Patancheru P.O., Andhra Pradesh, 502-324, INDIA.

IITA: The International Institute for Tropical Agriculture focuses on maize, pulses, rice, and root and tuber crops. Address: P.M.B. 5320, Ibadan, NIGERIA.

ILCA: The International Livestock Center for Africa works mainly in the area of integrating Livestock and crop production, and also does breeding work. Address: P.O. Box 5689, Addis Ababa, ETHIOPIA.

ILRAD: The International Laboratory for Research on Animal Diseases focuses on the eradication of trypanosomiasis (sleeping sickness) and theileriosis. Address: P.O. Box 30709, Nairobi, Kenya.

IRRI: The International Rice Research Institute developed the first high-yielding, semi-dwarf rice varieties back in the 1960's. Now it's focusing on developing types that need fewer production inputs. Address: P.O. Box 933, Manila, PHILIPPINES.

WARDA: The West Africa Rice Development Association works to promote rice self-sufficiency in 15 countries in West Africa. Address: P.O. Box 1019, Monrovia, LIBERIA.

Non-CGIAR Supported International Research Centers

AVRDC: The Asian Vegetable Research and Development Center focuses on tomatoes, Chinese cabbage, peppers, sweet potatoes, soybeans, and mungbeans. Address: P.O. Box 42, Shanua, Tainan, 741, TAIWAN, Republic of China.

ICRAF: The International Council for Research on Agroforestry. Address: P.O. Box 30677, Nairobi, Kenya.

IRIWB: The International Research Institute for Winged Beans, recently established in Sri Lanka. Address unavailable.

NFTA: The Nitrogen Fixing Tree Association promotes the use of N-fixing trees for Third World small farmers for the purpose of green manure, erosion control, firewood, and timber. Annual membership is U.S. \$10 (developed countries) and U.S. \$5 (Third World). Members receive 2 research journals ("Leucaena Research Reports" and "Nitrogen Fixing Tree Research Reports"), 6-10 "NFTA Highlights" (focusing on tree species), and 2 issues of "NFTA News". Other publications include "Leucaena Wood Manual" and "Leucaena Forage Manual". Address: NFTA,

P.O. Box 680, Waimanalo, Hawaii, USA 96795. Tel. (808) 259-8685.

WINROCK INTERNATIONAL: Created in 1985 through a merger of the Internat. Agric. Devel. Service, the Winrock Internat. Livestock Research and Training Ctr., and the Agric. Development Council. It is involved in crop and livestock research/extension programs throughout the Third World. Headquarters Address: Route 3, Morrilton, AR 72110, USA; Washington Address: Rosslyn Plaza, 1611 N. Kent St., Arlington, VA, USA 22209.

II. PRIVATE AND VOLUNTARY ORGANIZATIONS (PVO's)

Several PVO's provide unusually good technical support services for grass-roots agricultural development efforts.

ECHO: The Educational Concerns for Hunger Organization, Inc. is a non-denominational Christian organization that works with ag missionaries and other ag development workers. ECHO actively promotes grass-roots ag experimentation and technical networking. It publishes Echo Development Notes (EDN) at least quarterly, which provides very relevant technical information on small farmer crop and livestock production. EDN also serves as a valuable technical information clearinghouse and informs readers of useful references and sources of technical support. EDN is sent to Peace Corps country offices; for others involved in Third World ag development, a subscription is free. A set of back issues since 1981 costs \$10, postage paid and is well worth it. ECHO also maintains a seedbank and will send small trial packets. It welcomes visitors at its experimental/demo farm. ECHO intends to develop auto-tutorial ag training materials. Address: ECHO, RR #2, Box 852, North Ft. Meyers, FL 33903, USA; telephone (813)543-3246.

VITA: Volunteers in International Technical Assistance is a private, nonprofit, international development organization that provides a number of informational and technical services (by mail and through on-site consulting) that promote self-sufficiency. VITA's main areas of focus are agriculture, food processing, renewable energy, water supply and sanitation, housing, construction, and small business development. It also publishes a quarterly magazine and a variety technical papers, manuals, and bulletins. Address: VITA, 1815 N. Lynn St., Suite 200, Arlington, VA 22209, USA.

WORLD NEIGHBORS: A non-sectarian, international development organization that promotes grass-roots, self-help initiatives utilizing local leaders and local volunteers. They have developed an impressive collection of books, manuals, filmstrips, and flipcharts on agriculture, health, nutrition, family planning, and community development; these materials are available in English, French, and Spanish and are designed especially for comprehension by villagers in the Third World. World Neighbors produces 2 newsletters: 1) World Neighbors in Action, a quarterly how-to-do-it newsletter for \$5 a year (airmail postage); 2) Soundings from Around the World, a twice-yearly communications exchange newsletter that reviews World Neighbors' development materials. A catalog of their materials is available on request. Address: World Neighbors, 5116 North Portland Ave., Oklahoma City, OK 73112, USA; telephone (405) 946-3333.

Appendix H: A bibliography of useful references

NOTE: The International Research Institutes listed in Appendix G have some excellent references and troubleshooting guides available. The following catalog is a comprehensive guide to their publications and costs about \$10 (U.S.) :

Publications on Internat. Agric. Research and Development, 1983, GTZ-CGIAR-IRRI, available from the Agribookstore, Winrock International, 1611 N. Kent St., Arlington, VA 22209, USA.

AGRICULTURAL EXTENSION AND DEVELOPMENT

Africa in Crisis, L. Timberlake, 1985, Earthscan, 1717 Massachusetts Ave. NW, Washington, DC

20036.

Agricultural Extension, Manual M-18, PC/ICE, 1983.

Coming Full Circle: Farmers' Participation in the Development of Technology, P. Mation et. al., 1984, available from Agribookstore, Winrock International, 1611 N. Kent St., Arlington, VA 22209, USA. \$12.15.

Planning Technologies Appropriate to Farmers, D. Byerlee, 1980, available from Agribookstore (same address as above). \$7.60.

Two Ears of Corn, Roland Bunch, World Neighbors, 5116 N. Portland, Oklahoma City, OK 73112. 2nd ed., 1985. Cost: \$7.50 plus postage (\$0.50 overseas surface, \$5 overseas air. Also available through PC/ICE as publication AG-49.

AGROFORESTRY (See also Windbreaks)

Agroforestry in the Sahel, Fred Weber and Marilyn Hoskins, Virginia Polytechnic Institute and State Univ., 1983. Available through PC/ICE as publication FC125

Agroforestry In-Service Training, PC/ICE manure T-16, 1984.

Casuarinas: Nitrogen-Fixing Trees for Adverse Sites, 1984, National Research Council. Available from Nat. Academy Press, 2101 Constitution Ave., Washington, DC 20418, USA. Also available from PC/ICE as publication FC46.

Forestry for Food Collection, Food and Agric. Org., United Nations, 1979. Reprinted by PC/ICE as publication FC35.

Leucaena: A Promising Forage and Tree Crop for the Tropics, 2nd ed., 1984, National Academy of Sciences, available from Nat. Academy Press, 2102 Constitution Ave., Washington, DC 20418, USA. Also available from PC/ICE as publication FC15.

Proceedings of the Kenya National Seminar on Agroforestry, International Council for Research in Agroforestry, 1981. Available from PC/ICE as publication FC86

Workshop on Agroforestry Systems in Latin America, CIAT, 1979. Reprinted by PC/ICE as publication FC87.

CROP AND FORAGE PRODUCTION

Field Crops (General reference)

Guide for Field Crops in the Tropics and Subtropics, USAID, 1976. Reprinted by PC/ICE as publication R-10.

Handbook of Tropical Food Crops, ed. by F. Martin, 1984. Covers cereals, pulses, root crops, vegetables, and fruits. CRC Press, 2000 Corporate Blvd. N.W., Boca Raton, FL 33431, USA. \$94.50.

Traditional Field Crops, PC/ICE Manual M-13, 1981. Covers maize, sorghum, millet, cowpeas, beans, peanuts.

Cereal Crops

A Farmer's Primer on Growing Rice, IRRI, 1979, available from UNIPUB, 345 Park Ave. S., New York, NY 10010, USA.

Modern Corn Production, Aldrich and Leng, 2nd. ed., 1978. Available from Thompson Publications, Box 9335, Fresno, CA 93791, USA.

Pearl Millet, Rachie and Majmudar, Penn. State Univ., 1980.

Training Manual for Rice Production, IRRI, 1976, available from UNIPUB, 345 Park Ave. S., New York, NY 10010, USA.

Legumes (for food)

Food Legumes, Crop and Product Digest #3, 1979; Tropical Products Institute, 56/62 Grays Inn Rd., London WC1X8LU, U.K. Also available from PC/ICE as publication AG85.

Modern Soybean Production, Scott and Aldrich, 1979, Thompson Publications, Box 9335, Fresno, CA 93791, USA.

Tropical Legumes: Resources for the Future, 1979, National Academy of Sciences, Printing and Pub. Ofc., 2101 Constitution Ave., Washington, DC 20418. Available from PC/ICE as publication AG21. Covers leguminous root, pulse, fruit, and tree crops.

The Winged Bean: A High-Protein Crop for the Tropics, 1981 Nat. Academy of Sciences; available from Nat. Academy Press, 2101 Constitution Ave., Washington, DC 20418, USA.

Mixed Gardening and Fruit Trees

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