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ABSTRACT

This manual, prepared for use by Peace Corps volunteers in developing countries, has been designed as an on-the-job reference for soil management and fertilizer use at the small farmer level. It provides information on yield-boosting techniques, especially in the areas of soil conservation, organic and chemical fertilizer use, and the safe and appropriate use of agricultural chemicals. The text is written in a "how to" format, in as nontechnical language as possible, and takes a problem-solving approach to soil management and fertilizer use. Organized into nine sections, the text covers the following topics: soil basics, spotting and fixing soil physical problems, seedbed preparation, soil fertility basics, determining fertilizer needs, how to use organic fertilizers and soil conditioners, chemical fertilizers, liming soils, and salinity and alkalinity problems. An appendix to the manual provides conversion tables, composition of common fertilizers, information on soil moisture content, erosion control approaches, and hunger signs in common crops. (KC)

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SOILS, CROPS AND FERTILIZER USE

A WHAT, HOW AND WHY GUIDE

by

DAVE LEONARD

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Author's Foreword

Agriculture extension work requires more than good intentions and rapport with farmers. The real challenge is usually establishing credibility in the agriculture skills area.

Agriculture at the small farmer level in a developing country is a complex endeavor. Farmers have much they can teach you when it comes to land preparation, planting, harvesting, using tools, and other manual skills. Likewise, there are many yield-boosting skills you can show them, especially in the areas of soil conservation, organic and chemical fertilizer use, and the safe and appropriate use of agricultural chemicals.

This manual has been designed as an on-the-job reference for soil management and fertilizer use; hopefully, it will help you along that sometimes bumpy road to credibility.

I would like to give a special thanks to Susan Cass for the illustrations in this manual.

David Leonard

Please Note: Any suggestions for revisions or additions are welcome. Write to:

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PART I

STARTING FROM SCRATCH

Some Important Soil Basics

WHAT IS SOIL ANYWAY?

Most soils evolve slowly over centuries from the weathering of underlying rock material and decomposing plant matter. Some soils are formed from deposits layed down by rivers and seas (alluvial soils) or by wind (loess soils).

Soils have 4 basic components:

1. Mineral particles (sand, silt, clay)
2. Organic matter
3. Water
4. Air

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

WHY DO SOILS VARY SO MUCH?

Climate, type of parent rock, topography, vegetation, management, and time all influence soil formation and interact in countless patterns to produce an amazing variety of soils. It's not uncommon to find 2 or 3 different soils within one small farm that differ markedly in management problems and crop yield potential.

TOPSOIL vs. SUBSOIL

Dig down a couple feet in most soils, and you'll notice 2 distinct layers. The TOPSOIL is the darker, upper layer about 6-12" thick. Most of a crop's roots (like 60-80%) are found here, since topsoil offers much better conditions for root growth. That's because:

1. Topsoil is more fertile than subsoil because of its higher organic matter content (that's why it's darker) and because most fertilizer nutrients don't move downward after being applied to the topsoil layer.

2. Topsoil is looser (less compacted) than subsoil because: plows and hoes usually don't reach the subsoil; organic matter aids looseness; subsoils tend to be more clayey.

So what good is SUBSOIL if most of the action takes place in the topsoil?:

1. An average subsoil is much thicker than the topsoil and provides a vital moisture reserve during dry spells. It's estimated that about half the moisture needed to grow a crop of corn in the Corn Belt is already in the subsoil at planting time, while average rainfall during the crop's growth provides the other half.

2. Subsoil characteristics like drainage ability and nutrient content have a big influence on crop yields.

Making topsoil out of subsoil: Exposed subsoil (i.e. due to erosion) can be converted into productive topsoil over several years through large additions of organic matter (compost, animal manure, etc.) as long as there's enough total depth left (at least 18" or so). More on this in Part VI.

THE MINERAL SIDE OF SOILS: SAND, SILT, AND CLAY

It would take about 10,000 average size clay particles to equal an inch vs. only about 125 average sand grains. Silt is midway between in size.

Sand and Silt

Both sand and silt are just broken down rock fragments, mainly quartz (silicon dioxide). Silt particles are miniature sand particles. They don't usually contribute much soil fertility since quartz contains no plant nutrients and the particles carry no negative charge like clay and humus (see below). Some sands contain sizeable amounts of micas and feldspars which aid soil fertility, but this is uncommon. Despite their lack of nutrients, sand and the larger of the silt particles are very beneficial to soil tilth (ease of working), drainage, and aeration if present in moderate amounts.

Clay

Aside from their much smaller size, clay particles are uniquely different from sand and silt:

1. Clay particles have a negative charge: They act like magnets by attracting and holding those plant nutrients that have a plus (+) charge like ammonium nitrogen (NH_4^+), potassium (K^+), calcium (Ca^{++}), magnesium (Mg^{++}), and several others. This greatly cuts down on nutrient losses from the downward movement of rain or irrigation water (called leaching losses).
2. They have a tremendous surface area: Each clay particle is a laminated structure of platelike units. This lattice makeup plus small size means a huge surface area for attracting plus charged nutrients. One cubic inch of clay particles easily has 200-500 sq. ft. of surface area.
3. They furnish some plant nutrients: Unlike the sand and silt particles, clays are aluminum-silicate minerals and also contain varying amounts of potassium, calcium, magnesium, iron, and other nutrients. A good part of a soil's natural fertility comes from its clay fraction, but this varies a lot with the type of clay (see below).

How Clays Differ

There are a number of different clay types, and most soils contain at least 2. The clays found in most temperate zone soils differ in several important respects from those that predominate in many tropical soils where weathering has been more intense.

The 2:1 silicate clays dominate the clay portion of most temperate zone soils (the ratio refers to the proportion of silicate to aluminum). Soils with a high content of 2:1 clays are very sticky and plastic when wet and may form large cracks upon drying. They also have a relatively high negative charge (good for holding large amounts of plus charged nutrients).

In many well drained and weathered tropical and sub-tropical soils, the clay fraction is dominated by the 1:1 silicate clays and the hydrous oxide clays of iron and aluminum. That's because centuries of weathering and leaching have removed a lot of silicate. Unlike the 2:1 clays, these "tropical clays" are much less sticky and plastic and have better tilth comparatively. However, they tend to have much lower natural fertility (a lot of their nutrients have been leached out) and a much lower negative charge (less nutrient holding ability).

IMPORTANT POINT!: Note that good drainage (favorable to leaching), lots of rainfall, a warm climate, and centuries of weathering are needed to form a true tropical soil (one whose clays are mainly 1:1 and hydrous oxides). Many soils in the tropics and sub-tropics are relatively young, poorly drained, or have formed under low rainfall; such soils are more likely to contain mainly 2:1 temperate type clays in their clay portion; some may be a mix of both kinds. A distinct red or yellow color, especially in the subsoil, is a sign of extensive weathering under good drainage and usually means that "tropical" clays dominate the soil's clay portion.

SOIL ORGANIC MATTER

Most actively cropped soils contain only 2-4% organic matter in the topsoil (by weight). Despite its small proportion, organic matter plays a vital role in crop production:

1. It greatly improves soil physical condition (tilth) by loosening up clayey soils and tightening up sandy soils. Benefits are very noticeable at about the 5-6% level.
2. It markedly increases the water holding capacity of sandy soils.
3. It's an important storehouse and supplier of nutrients (especially nitrogen, phosphorus, and sulfur) which are slowly released as organic matter decomposes. It's estimated that for each 1% organic matter in the topsoil, a yield of 10 bushels (560 lbs.) of corn can be obtained per acre (600 kgs./hectare) without additional fertilizer.
4. The tiny particles of partially decomposed organic matter are known as HUMUS and have a very high negative charge compared to most clays. Humus can account for a large share of a soil's nutrient holding capacity, especially in sandy soils or true "tropical" soils. It can hold up to 30 times more nutrients than clay.
5. Humus helps protect phosphorus and other nutrients from becoming tied up in the soil (see p.46).
6. It cuts down soil erosion by binding soil particles into a crumb like structure that resists being carted away by flowing water. It also lessens water runoff by making the soil more permeable to rainfall.

Organic Matter Does Wonders for Soil, BUT there's a Catch

A virgin forest or grass soil has a healthy organic matter content (like 6-9%) in the topsoil. Trouble is, once you start cropping it, this level can decline rapidly for 3 reasons:

1. Plowing and hoeing aerate the soil, and this stimulates the microbial breakdown of organic matter. Sure, it may be thrilling to watch old roots, leaves, and stalks gradually turn crumbly, but the process keeps on going right past the humus stage til there's nothing left.
2. Forest and grass recycle high amounts of organic matter back to the soil through leaf drop and dead roots, but most cultivated crops can't come close to matching this.
3. Crops grown in rows expose the soil to higher temperatures which accelerate organic matter breakdown.

So what's to keep you from maintaining or building up organic matter levels by adding compost, manure, etc? It usually isn't feasible except on small areas like home vegetable* gardens because:

1. It takes a huge amount of organic matter to raise the humus level by even one percentage point (i.e. from 3% to 4%). Each 1% soil organic matter equals 20,000 lbs./acre (22,000 kgs./hectare). It takes 40,000 lbs. of fresh organic matter to end up with 20,000 lbs. of humus (partially decomposed organic matter, o.m.).
2. The problem of organic matter breakdown is especially serious in the tropics due to higher temperatures; decomposition takes place 3 times as fast at 90°F than at 60°F. That's one big reason why the vast majority of successful organic gardening projects are located in temperate climates. For large areas, though, it's no picnic trying to raise o.m. levels even in a cool climate. In an experiment in New York, adding 25 tons of stable manure per acre per year raised the topsoil o.m. level only 2 percentage points after 40 years. The trick is to concentrate on smaller areas where you can apply high amounts without hiring a supertanker.

Despite the uphill battle, there are a number of things you can encourage your farmers to do to at least minimize

*Vegetable will be shortened to vegie for the rest of this manual.

organic matter losses. We'll get into the nitty gritty details in Chapter VI, but here's some general advice:

1. Encourage farmers to return all crop residues to the soil except in the case of special disease or insect problems.

2. Don't prepare land by burning if another method is feasible.

3. Make applications of manure and compost; unless a farmer can buy manure or has a good number of animals in confinement, it'll be hard to come up with enough for anything but a small area. More on this on p.57. Compost is practical only for small areas.

4. Limit tillage operations (plowing, disking, hoeing) to the minimum needed for adequate seedbed preparation and weed control.

5. Rotating low residue crops like vegies and cotton with medium residue (corn, sorghum, rice) or high residue (pasture grass) crops will help, but few small farmers have this type of flexibility.

6. If liming is needed to lessen soil acidity (raise the pH), avoid excessive applications since they increase microbial breakdown of o.m. Never lime a soil to a pH above 6.5. Chapter 8 is devoted to liming.

7. Green Manure Crops: That's a term used for growing a crop like cowpeas, soybeans, oats, etc. and plowing it under in the green, immature stage to add organic matter (legumes like cowpeas and soybeans will also add nitrogen to the soil). In some cases it's a good idea, but here's the problem:

   a. Not many small farmers will want to tie up their land growing a non-cash crop.

   b. The effect of green manure crops is short lived in the tropics.

   c. The green manure crop may use up soil moisture needed for the next crop.

In short, you've got the best chance for maintaining or raising soil o.m. content on small areas. It'll be a real battle on larger fields.

MORE ON SOIL MICRO-ORGANISMS

The soil is a tremendous biological lab with a teaspoonful containing easily a billion micro-organisms. Some cause plant diseases, but most are beneficial:

1. They make humus: Many kinds of soil bacteria and fungi break down fresh organic matter into crumbly humus (partially decomposed o.m. that does all those great things for soil).

2. They release plant nutrients tied-up in o.m.: Most of the nitrogen, phosphorus, and sulfur in fresh plant residues is tied up in the organic form which plant roots can't use. Soil microbes convert these tied-up nutrients into the in-organic (mineral) form in the process of breaking down o.m. and make them available to plants. For example, microbes convert unusable organic nitrogen to the available ammonium and nitrate forms like so:

$$\text{ORGANIC NITROGEN (unavailable)} \xrightarrow{\text{microbes}} \text{AMMONIUM NITROGEN } (NH_4^+) \text{ (available)} \xrightarrow{\text{microbes}} \text{NITRATE NITROGEN } (NO_3^-) \text{ (available)}$$

3. Nitrogen Fixation: Several types of bacteria can "fix" nitrogen from the air and convert it to a form that plants can use. The most important type is the Rhizobia bacteria that form pea-like nodules on the roots of legumes (plants that produce their seed in pods like peanuts, beans, peas, clover, alfalfa, soybeans). The Rhizobia have a symbiotic (mutually beneficial relationship with the legume; they get fed with sugars from the roots and supply the host legume with N taken from the air. Most pasture legumes like alfalfa, kudzu, clovers, and siratro need no fertilizer nitrogen thanks to the Rhizobia. Soybeans, peanuts, and mung beans need little or no extra N as long as the proper strain of Rhizobia is present. Beans, peas, and lima beans are less efficient N fixers and usually need some fertilizer N.

   Aside from Rhizobia, blue-green algae can fix useful amounts of N in flooded rice soils. Azotobacter are free-living N fixing bacteria commonly found in warm climate soils. Even so, non-legumes need nitrogen supplied from chemical and/or organic fertilizers.

PART II

SOIL PHYSICAL PROBLEMS

How to Spot Them and Fix Them

DOWN TO EARTH: Getting to Know your Area's Soils

It's very hard to make any useful generalizations about the soils of the tropics and sub-tropics. Remember that climate, parent rock, topography, time, vegetation, and management interact in countless patterns. Don't be surprised to find several kinds of soil on one small farm that vary markedly in depth, slope, drainage, water holding capacity, texture, tilth, pH, and fertility. Here's how to get to know your area's soils:

1. You'll usually get the most useful info on local soils by talking with the farmers who earn their living from them and by examining them yourself.
2. Get hold of any soil survey reports or other soil studies on your area.
3. Get a competent extension agent or agronomist to spend some time in the field with you.

This chapter focuses on soil PHYSICAL PROBLEMS that can cut crop yields; they're every bit as important as soil FERTILITY PROBLEMS (i.e. nutrient deficiencies, too acid or alkaline a soil) which we'll cover in Part IV.

Some Common Soil Physical Problems

Shallow soil

Excessively rocky soil

Soil compaction and hardpans

Low water holding capacity

Poor drainage

Crusting of surface soil that prevents seedling emergence or water intake

Soil erosion

HOW TO SPOT AND TREAT SOIL PHYSICAL PROBLEMS

Using a shovel (or soil probe or auger) and a homemade slope meter you can check out the 6 vital signs of soil physical health: TEXTURE, TILTH, WATER HOLDING CAPACITY, DRAINAGE, DEPTH, and SLOPE.

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

What About Soil Color?

The darker the soil, the richer it is, right? Not always. In some areas like prairie grasslands of the Great Plains there is (or was) a direct relationship between color and humus content - the more black, the more humus. However, in many other areas, especially the tropics, there's often little connection between blackness and humus content. In warmer climates, humus doesn't often have a black color but tends to be brown; parent rock can make a soil brown too. Some deep black soils in the tropics owe their color not to high humus content but to a reaction of calcium in their limestone parent material with only a small amount of humus.

How about red and yellow colors? They usually indicate extensive weathering and oxidation (i.e. good drainage); dull greys and blues, especially in the subsoil, are a sign of poor drainage. More on that on p.18.

OK, so let's talk about the 6 major features of soil physical health.

I. SOIL TEXTURE

Texture refers to the relative amounts of sand, silt, and clay in a soil; it has nothing to do with humus. Texture has a big influence on soil productivity and management needs, since it affects tilth, water holding ability, drainage, erosion potential, and soil fertility.

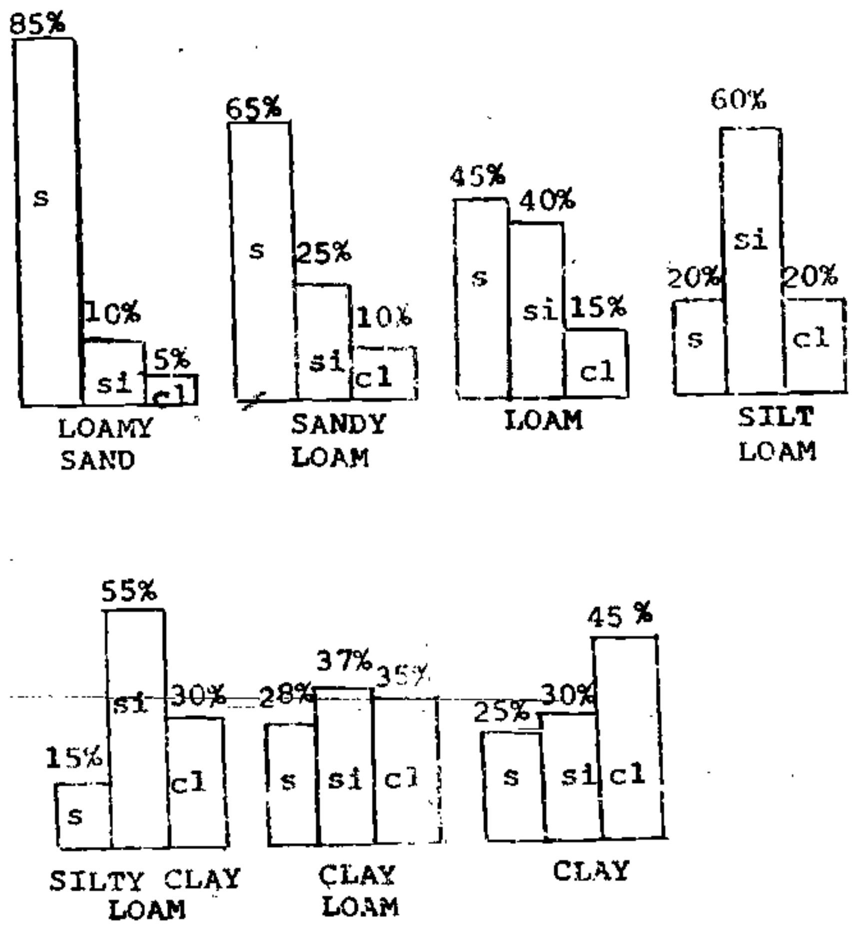
Texture usually varies with depth: The subsoil tends to be more clayey than the topsoil, though the reverse may sometimes occur.

There are 3 basic texture groups: SANDS, LOAMS, CLAYS. They can be sub-divided further:

SANDS (Coarse textured soils)	LOAMS (Medium textured)	CLAYS (Fine Textured)
Sands	Sandy loams	Sandy clays
Loamy sands	Loams	Silty clays
Gravelly sands	Silt loams	Clays
	Clay loams	Gravelly clays
	Silty clay loams	Stony clays
	Gravelly loams	

Here are the relative %'s of sand, silt, and clay according to soil texture:

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



Checking Out Soil Texture in the Field

Don't worry about distinguishing all the textural types, but you should be able to tell the difference between a SANDY, LOAMY, and CLAYEY soil. You can do that and then some by using the guidelines below:

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 readily when released. If wet, if forms a cast that crumbles w/o 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 w/o breaking.	A bit gritty but slightly plastic.
SILT LOAM	Cloddy but clods are easily broken.	Same as above.	Only slightly gritty and plastic; has a talcum like feel.
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 pinched between thumb and fore-finger but it breaks easily.
CLAY	Hard lumps or clods when dry.	The wet cast can be tossed and caught repeatedly w/o breaking.	Very sticky & plastic; forms a ribbon easily.

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

Sands (Coarse Textured Soils)

Sandy soils are easily tilled, resist compaction, and have good drainage and aeration - all good qualities for encouraging root growth. However, they have a low water holding capacity, tend to dry out quickly, and are likely to be low in natural fertility. They tend to be low in clay and humus, making for little negative charge to keep plus charged nutrients from leaching (see p. 37). Another reason leaching is a serious problem in sandy soils is that water passes through them so rapidly. However, this does make them more resistant to soil erosion losses by rainfall, since water tends to penetrate rather than to run off as it does on clayey soils.

Despite the long list of cons, sandy soils are among the most productive vegetable soils due to their good drainage (fewer disease problems) and tolerance of frequent machinery traffic without compaction problems.

Loams (Medium Textured Soils

A true loam soil combines the good points of both sandy and clayey soils without the bad ones. Sandy loams show the negative traits of sandy soils to some degree, while clay loams tend to have some of the problems of clay soils.

Clays (Fine Textured Soils)

Pros:

1. High water holding capacity; they hold at least twice as much available water per foot of depth than sandy soils. That makes them more drought resistant and less prone to leaching.
2. They tend to have a higher negative charge than sandy soils for 2 reasons: more clay particles, and they also tend to have more organic matter than sandy soils. This makes for less leaching of plus charged nutrients (see p.39). However, true tropical clays have a much lower charge than temperate type clays.
3. They tend to have higher natural fertility than sandy soils, but not always.

Cons:

1. They're more prone to poor drainage.
2. They're easilycompacted by machinery, animal, or foot traffic.
3. They're harder to plow or hoe, not only in terms of power, but in terms of ideal moisture range. If worked when too wet, they compact and stick. If tilled when too dry, they're overly hard and cloddy.
4. Soils high in clay tend to crust over and inhibit seedling emergence (silt can do this too).
5. Most clayey soils have a slow water absorption rate, making them more susceptible to erosion by water runoff.

CAUTION! Don't Over-generalize!

Don't take the above comparison of sandy, loamy, and clayey soils too rigidly. Clayey soils aren't necessarily poorly drained (especially if on a slope) or high in natural fertility. All sandy soils aren't low in natural fertility either. Clayey soils are probably the most variable of the 3 groups.

HOW TO IMPROVE CLAYEY AND SANDY SOILS

There's lots of hope if you're working with a small area:

1. Add sand to clay or clay to sand.
2. Add organic matter to both. Compost, manure, rotted coconut husks, seaweed, and sugar mill filter press cake (cachaza) will loosen and fluff up clayey soils and help tighten up sandy soils and increase their water holding capacity. They also supply plant nutrients. Sawdust, rice hulls, and cottonseed hulls will help loosen a clayey soil but don't do much for sandy soils or have much fertilizer value. Don't expect quick results; it may take several years of high application rates (like 1 lb./sq. foot or about 5 kgs./sq. meter). We'll cover organic fertilizers and soil improvers in Part VI.
3. Use a 2-3" layer of mulch between the plants. Rice hulls, peanut hulls, rice straw, grass, sawdust, etc. all make good mulch. It'll keep sandy soils from drying out quickly and encourage earthworm activity (good for loosening up clays). Mulching has many other benefits, and we'll cover 'em all in Part VI.
4. Keep animals, machinery, and feet off clayey soils when they're wet to avoid compaction.
5. In poorly drained clayey soils plant crops on raised beds or ridges during the high rainfall season. Planting on the flat or in a furrow bottom is usually recommended for sandy soils when moisture is likely to be short.

II. SOIL TILTH

Tilth refers to a soil's physical condition. A soil in good tilth is easily worked, crumbly, and can readily take in water when dry. A soil in poor tilth is hard to work, cloddy, and absorbs water slowly when dry. Texture, organic matter, and moisture content all influence tilth. Soil tilth isn't static like texture either; the tilth of a clayey soil changes markedly with moisture content.

Tilth is mainly a problem of clayey soils, though the overly loose condition of sandy soils might be considered a poor tilth factor.

HOW TO MAINTAIN OR IMPROVE SOIL TILTH

Apply Organic Matter

Organic matter is the big key to good tilth, since it fluffs up clayey soils and binds together sandy soils. Problem is that it takes regular additions (like several times a year) of hefty rates to do much good. Few farmers have access to enough o.m. to cover anything more than a small area adequately. Slot treatment is one way around this (p.61).

Limit Tillage Operations

Tillage can be good and bad for tilth. Under favorable moisture conditions, plowing or hoeing breaks up clods into smaller aggregates and loosens soil for a more favorable seedbed. However, stirring and shearing the soil stimulates the microbial breakdown of o.m. Repeated machinery or animal traffic compacts the soil. Farmers using mechanized equipment tend to overdo tillage (especially harrowing and rototilling).

Type of Crop

Crops like cotton, tobacco, peanuts, potatoes, and vegies require frequent cultivation and machinery traffic and also return a relatively small amount of crop residue to the soil. Soil tilth will suffer unless additional o.m. is supplied or a crop rotation used. Corn, sugarcane, sorghum, and rice are less harmful to soil tilth since they return more residues (unless burning is used) and usually require less seedbed preparation and cultivation.

Putting land into temporary grass or grass-legume pasture will greatly improve tilth; however, the effects are likely to be short-lived in the tropics and may only last a year once land is reverted to row crops again. Anyway, few small farmers have this type of cropping flexibility (livestock are a costly and long term investment).

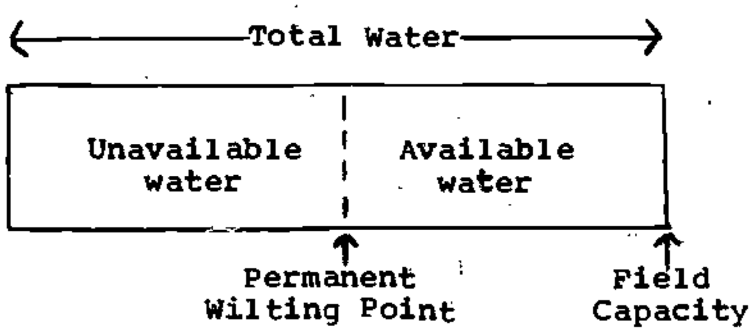
III. SOIL WATER HOLDING CAPACITY

How Soils Hold Water

About half the soil's volume is pore space occupied by air and water. Soils hold water much like a sponge. If you soak a sponge in water and then lift it out, some of the water will drain off even if you don't squeeze it. The same thing happens with soil after a rain or irrigation. Like the sponge, a good deal of water remains in the soil after the excess has been drained off by gravity. The soil is now said to be at FIELD CAPACITY, and the retained water is held in the form of films which are attracted and held to the surfaces of soil particles (this has nothing to do with negative charge).

The catch is that only about HALF the water held at field capacity is actually available to plants; they'll wilt and die long before the soil is completely dry. That's because much of the water is too strongly held to the soil particles for plant roots to utilize. As soil moisture gets used up by roots and evaporation, the water films get thinner and the force of retention stronger. If more water isn't added, plant roots reach a point where they can no longer counter the force by which water is held by the soil EVEN THOUGH THE SOIL STILL CONTAINS ABOUT HALF THE WATER IT HAD AT FIELD CAPACITY. This is called the PERMANENT WILTING POINT, and plants will die unless water is added.

AVAILABLE WATER is that portion held between field capacity and the permanent wilting point:



How Soils Lose Water

Soils lose water by plant transpiration, surface run-off, surface evaporation, and drainage. Drainage (gravity) removes only the surplus water held above field capacity. The rest is too tightly held by the soil particles to be drained off.

Plant transpiration uses up lots of water; something like 25-75 gals. of water is transpired into the atmosphere for every pound of dry matter produced.

Soil surface evaporation losses may sometimes equal transpiration losses in high rainfall regions and usually exceed transpiration losses in drier regions. All the more reason to use mulch whenever possible (see p. 67).

Surface runoff losses are important on slopes, especially on clayey soils with low intake rates. One important side benefit of soil conservation measures like contour planting and terracing is that sloping fields retain more water for crop growth. Many Volunteers have reported crop yield increases due to soil conservation practices.

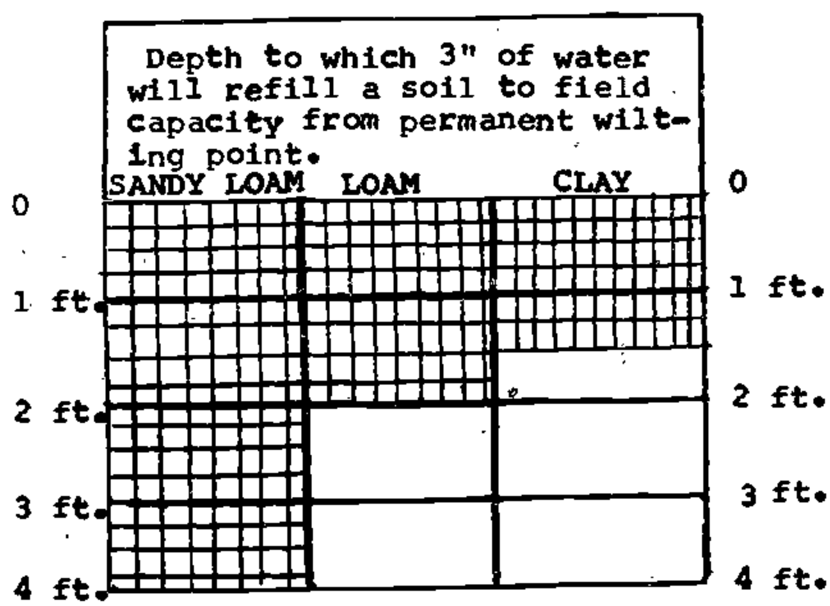
How Soil Texture and Organic Matter Influence Water Holding Capacity

Texture has a big influence on water holding capacity:

	Inches of Available Water Held per ft of Soil
Sands	0.25 - 0.75"
Loamy Sands	0.75 - 1.25"
Sandy Loams	1.00 - 1.50"
Fine Sandy Loams	1.50 - 1.75"
Clay Loams	1.75 - 2.5"
Clays	2.00 - 2.5"

Humus (partially decomposed organic matter) increases water holding capacity, especially in sandy soils.

Now take a look below:



Depth to which 3" of water will refill a soil to field capacity from permanent wilting point.

HOW MUCH WATER DO PLANTS NEED? HOW OFTEN?

That depends on soil texture, stage of growth, rooting depth, temperature, relative humidity, and wind. Here's some basic guidelines:

1. Sandy soils need more frequent (about twice as often) but lighter waterings than clayey soils since they can store only about half as much water per foot of depth.

2. The shallower the root system or the soil, the more often watering is needed. Tiny vegie seedlings with roots only an inch or so deep may need watering 1-2 times a day on a very sandy soil or once every 1-2 days on a clayey soil. As roots grow deeper, watering intervals can be spread out. However, well-established lettuce or other naturally shallow rooted crops will need more frequent (but lighter) waterings than field corn or other deep-rooted crops.

Rooting Depths of Crops When
There's no Barrier to Penetration

(18-24") Shallow	(36-48") Moderately Deep	(More than 48") Deep
Broccoli	Beans	Asparagus
Brussels sprouts	Beet	Bean, lima
Cabbage	Carrot	Parsnip
Cauliflower	Chard	Pumpkin
Celery	Cucumber	Field corn
Chinese cabbage	Eggplant	Sorghum
Garlic	Muskmelon	Squash, winter
Lettuce	Mustard	Sweetpotato
Onion	Pea	Tomato
Parsley	Pepper	Watermelon
Potato	Squash, summer	Sugarcane
Radish	Turnip	
Spinach	Rice	
Sweet Corn		

3. Plant demand for water increases with growth and reaches a peak around flowering or fruiting time (moisture stress at this time can really hurt yields). In warm weather, most very young crops will use about ½-1"* of water per week (sum of soil evaporation + plant transpiration). Peak usage rates for old crops run around 1¼-2¼" a week, depending on crop type, temperature, wind, and relative humidity.(high wind, temperature, and low relative humidity raise crop water needs).

4. Most common mistake is to overwater young plants and underwater older ones. Shallow watering encourages a shallow root system; roots won't penetrate into dry soil.

*A layer of water 1" deep = 7 gal/m^2.

Overwatering can cause drainage problems and leaching losses of nutrients like N. Farmers in low rainfall, irrigated areas will often pre-irrigate the soil to full rooting depth before planting to avoid getting behind later in the season.

4. Once roots are well established, shoot for a watering application of 1-2½" per irrigation depending on soil texture, plant demand, and depth of rooting.

How to Measure the Depth of Watering: Use a 1/2" diameter iron rod slightly tapered at one end and about 2-4' long. Wait about a day after a rainfall or irrigation and push the rod into the soil; it'll penetrate readily til it strikes dry soil (unless there's a hardpan).

You can measure the amount of water applied by rainfall or sprinkler irrigation using a tin can or rain gauge. Amounts below a quarter inch aren't too useful since they can be quickly lost by evaporation from the upper soil surface. Keep accurate rainfall records!

Deciding When to Water: Don't wait for plants to show visible moisture stress signs. Wilting, leaf rolling, or in some crops (like beans) a blue-green color are all signs of water need and can cut yields, especially at flowering or pollination.

A good guide is to apply water before one half of the root zone's available water has been used up. Plants take about 40% of their water needs from the top quarter of the root zone; once this top quarter gets down near 0% available water, it'll soon be time to apply more. You can estimate the percentage of available water by squeezing the soil in your hand and using the table in the Appendix (p. 152). Don't confuse this test with the texture test!

A reasonably accurate method is to figure that most well established crops will use about 2 inches a week. [It will take 7 gallons per square meter to apply 1 inch of water, i.e., 0.6 gal/sq. ft.]

IV. SOIL DRAINAGE

All major crops except rice need oxygen from the soil so they can take in water and nutrients. A poorly drained soil lacks enough oxygen in its pore spaces for good growth. Drainage is the soil's ability to get rid of excess water (both surface and subsurface water) and is affected by topography, depth, texture, and hardpans.

How to Spot Drainage Problems

1. Topography: Soils with a slope seldom have drainage problems; flat soils or the depressions in undulating fields should be suspect.

2. Crop Appearance: Crops in poorly drained portions of a field will be noticeably shorter and yellower and have standing water around them for a day or more after a good rainfall or irrigation.

3. Testing for Poor Drainage: Dig a hole 2-3 ft. deep and fill with water; allow to drain, and refill it again; the water level should drop at least 1" every hour and disappear in 24 hours. If not, only shallow rooted crops are likely to grow well.

4. Subsoil Color as a Drainage Indicator: Red, reddish-brown, and yellow subsoil color usually means good drainage; it means that the soil's iron and manganese are in the oxidized form (i.e. oxygen is present). Dull greys and blues mean poor drainage. Some soils alternate between good and poor drainage (like wet season vs. dry season); if so, the subsoil will have alternate streaks of bright and dull colors (called mottling).

5. Hard pans can restrict drainage.

Coping with Drainage Problems

1. Surface drainage problems (i.e. standing water) can often be cured by digging drainage ditches or by land leveling to smooth out depressions.

2. Subsurface drainage problems aren't as easily cured. Planting crops on raised beds or ridges is a big help. Subsurface tile drain systems are used in the U.S. Sometimes deep tillage can break up a hardpan layer that impedes downward water movement. Sometimes rice is the only feasible crop where there are no drainage remedies.

3. If hard pan restricts drainage, double digging or other form of deep tillage may be effective, though benefits may be temporary.

Seed Boxes have Special Drainage Problems

Shallow containers only a few inches deep are used to start out some vegie seedlings that are to be transplanted. Unless you use a super coarse soil mixture, drainage problems are likely. That's because there's no suction force to aid in drawing water down once it reaches the bottom of the container. The same thing happens when you hang wet clothes on the line. If you use normal soil in a shallow container, at the very least the bottom half will be too poorly drained for root growth; even the soil in the seed zone can remain so wet that germination is severely affected. We'll get into making a good container soil in Part III.

V. SOIL DEPTH

There's often a big difference between soil depth and useful soil depth. Compaction, hardpans, and poor drainage can all restrict root growth even on very deep soils. If you're working with a soil that's 6 ft. deep but the water table is only 3 ft. below the surface, you've barely got 3 ft. of useful soil. High subsoil acidity can limit root growth too (see p.41).

Here's a semi-helpful depth classification:

	Depth (Topsoil + Subsoil)
Deep soils	36" or more
Mod. deep soils	20-36"
Shallow soils	10-20"
Very shallow	less than 10"

Of course, it makes a big difference what lies beneath (i.e. solid rock vs. gravel vs. porous limestone) in terms of drainage.

Coping with Depth Problems

On a small area, you can always add more soil to build up depth. If stuck with a very shallow soil, you're usually better off growing shallow rooted crops (see table on p.17) Potatoes, onions, radish, cabbage, and lettuce are likely to cope with shallow soil better than field corn, tomatoes, or okra.

Remember that just because a crop is deep rooted doesn't mean that its roots will grow deep (even in a deep soil).

VI. SLOPE AND EROSION CONTROL

Slope is usually measured in terms of percent rather than degrees. Land with a 10% slope has a drop of 10 ft. for every 100 ft. of horizontal distance (or a 10 meter drop per 100 meters of horizontal distance). A 100% slope has one foot of fall per one foot of horizontal distance and equals 45 degrees.

A field's slope has a big effect on the amount of water runoff and soil erosion. In high rainfall areas, soil conservation measures are needed once the slope gets over 1-2%. An unprotected soil with a 4-5% slope can easily lose 50 TONS of soil per acre yearly. Here's some more scare figures:

1. Doubling the slope increases erosion losses by 150%.

2. Doubling the length of slope increases soil losses by 50% (more chance for water flow to build up and gain speed). The soil transporting power of flowing water varies with the 6th power of its velocity.

Soil Erosion's Toll

1. It carts away the best part of the topsoil. The smallest soil particles are the ones most easily moved, and that means the clay and humus particles that have so many nutrients and other benefits. The eroded material is usually 2-5 times richer in nutrients than the topsoil from which it came.
2. It destroys productive crop and forest land through soil removal and gulley formation.
3. It silts up rivers and streams and hydro-electric dams.

How to Measure Soil Slope

No need for a store-bought inclinometer; you can measure slope accurately enough using one of these 2 methods:

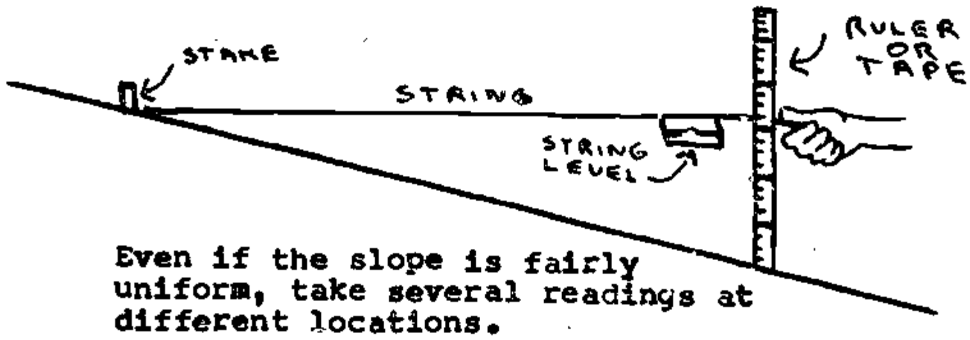
Method 1: Get hold of a carpenter's string level ("nivel de pita" in Spanish) and hang it on a string at least 100 inches long.

Anchor one end of the string to the ground using a small stake; hold the other end of the string directly downslope from the string and raise it til the string level shows a level grade.

Measure the vertical distance between the end of the level string and the ground. That gives you the vertical drop. Determine the slope % like so:

$$\% \text{ slope} = \frac{\text{Vertical drop (in inches or cms.)}}{\text{String length (in inches or cms.)}}$$

It's really easy if the string is 100 inches long, because the vertical drop in inches equals the % slope directly. However, 100" is too short for an accurate measurement unless the slope is very uniform and smooth. 200" would be better. Whether you use inches or centimeters, picking a round number makes division easier.



Even if the slope is fairly uniform, take several readings at different locations.

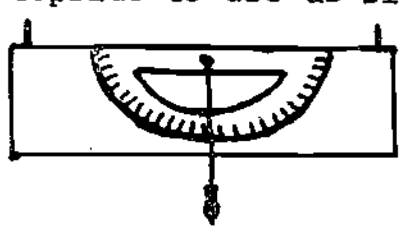
<u>Sample Problem</u>: Suppose your string is 400 centimeters long (4 meters) and that you measure a vertical drop of 36 centimeters. The slope would be:

$$\% \text{ slope} = \frac{36 \text{ cms.}}{400 \text{ cms.}} = \frac{9}{100} = 9\%$$

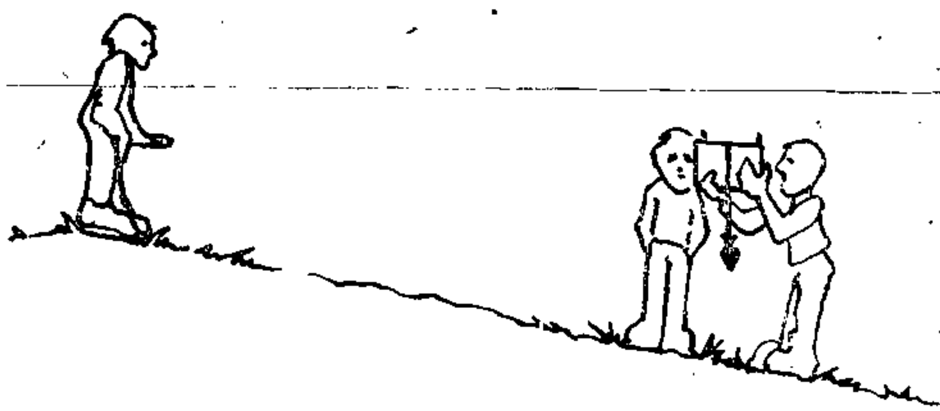
<u>Method 2</u>: This one gives you the slope in degrees which you'll then need to convert to percent, but it's still pretty easy.

A. Grab a flat piece of board about 10-12" long, 4-6" wide, and ½-1" thick. Glue a 6" long plastic protractor to it like so:

B. Anchor a nail in the center of the protractor's flat side. Suspend a thin string or thread from the nail and tie a small weight on the end so that it clears the degree quadrant and the board. Afix a nail at each end of the board's topside to use as sights, and you're ready.



C. You'll need 2 assistants. Stand face to face with one assistant and find what part of her/his body your eye meets, e.g. nose, forehead. Send her/him directly upslope from you about 20 feet or so. Hold the slope indicator up to your eye. Aim it at your assistant. Align the nail sights at the same part of the assistant's body where your eye height had reached, e.g. nose, forehead. Assistant #2 then reads off the degree mark crossed by the hanging string.



D. If the string rests on the 84° mark, then the actual slope angle is 6° (i.e. 90° - 84° = 6°). Use the table on page 153 to convert degrees slope to percent slope.

THE DYNAMIC DUO: Raindrop Splash and Surface Flow

Before getting into soil conservation methods, it helps to know your enemy. Raindrop splash and surface flow are the culprits when combined with soil slope.

Raindrop Splash: Raindrops act like miniature bombs whose hammer-like action does several nasty things:

1. It compacts the soil surface which reduces intake and increases run-off of water.
2. It breaks down clods and crumbs and moves the separated particles by splash.
3. It keeps particles in suspension which helps surface flow cart them away.

Raindrop splash is no big deal on flat ground as far as erosion, but when combined with slope it's bad news.

Surface Flow: One acre-inch of water weighs 113 tons. On 2-4% gentle slopes you're more likely to see sheet erosion, a uniform removal of soil. As slope and rainfall increase, water flow tends to channelize and cause rill and gulley erosion (a rill is just a small mini-gulley).

Most erosion control methods are geared to reducing surface flow, although there are ways of minimizing raindrop splash (we'll cover both).

Is Slope the Only Factor in Erosion Susceptibility?

Slope is definitely the biggie, but there are several other factors:

1. Rainfall Amount and Intensity: Intensity is much more important than rainfall total, and the tropics are notorious for torrential cloudbursts.
2. Amount of Ground Cover (crop cover or mulch): Row crops leave much of the soil exposed, resulting in much more erosion than denser crops like small grains, sugarcane, and especially pasture. Take a look at the results of a trial run in Puerto Rico on 40% slopes and 80" yearly rainfall: (next page)

Cropping Pattern	Annual Soil Losses in Tons per Acre
Bare soil	126 tons
Rotation (sweetpotatoes, corn, etc.)	17.5
Sugarcane	7.5
Pasture grass	1.2

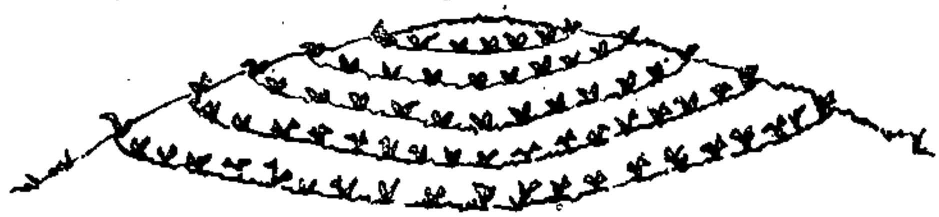
Mulching (see p.67) is another highly effective way of combatting raindrop splash. One study showed a 75% decrease in erosion from leaving 750 lbs. of straw per acre on the surface. Mulching also cuts down water runoff by preventing raindrop splash from compacting and sealing off the soil surface.

3. Soil Tilth and Permeability: Soil organic matter helps maintain a crumblike structure that resists being broken down by raindrop splash and also keeps soils more permeable. Sandy soils have lower erosion losses than clays since their large particles are more resistant to transport. They're also more permeable.

SOIL CONSERVATION METHODS

Under small farmer conditions, there are 4 conservation methods of varying effectiveness (aside from mulching and crop rotation). They all involve soil engineering:

1. Contour Cropping: This means running your plow furrows and crop rows on the contour instead of up and down. It's most effective on 2-8% slopes not more than 300 feet long and will reduce soil losses by about 50%. On slopes over 8%, contour plowing by itself becomes increasingly less effective unless combined with a terracing or ditch-bank system.



2. Contour Stripcropping: Strips of dense crops such as grass and small grains are alternated with strips of row crops; it's most effective on 2-12% slopes less than 400 ft. long.

3. Contour Ditch & Barrier System: This system is reasonably effective up to slopes of 45%. Small ditches running on the contour are dug at intervals down the slope (the steeper the slope, the closer the ditches). The excavated soil is placed on the downhill side of the ditch to act as a dike. A foot-wide live barrier of coarse growing grass (elephant, guinea, etc.), pineapple, or sisal is planted just above the upper side of the ditch to aid in soil retention. Crops are planted on the contour. The ditches have a ½-1% slope to aid water flow and lead to a grassed waterway.

4. Rock Walls: Soil conservation PCV's in El Salvador have successfully used rock walls on hilly farmland that's full of rocks. The walls are built on the contour at intervals down the slope and collect soil that would otherwise be lost. Over time this system helps lessen slope as the soil piles up in front of the walls which are about 1½-2 ft. wide and 3-4 ft. high.

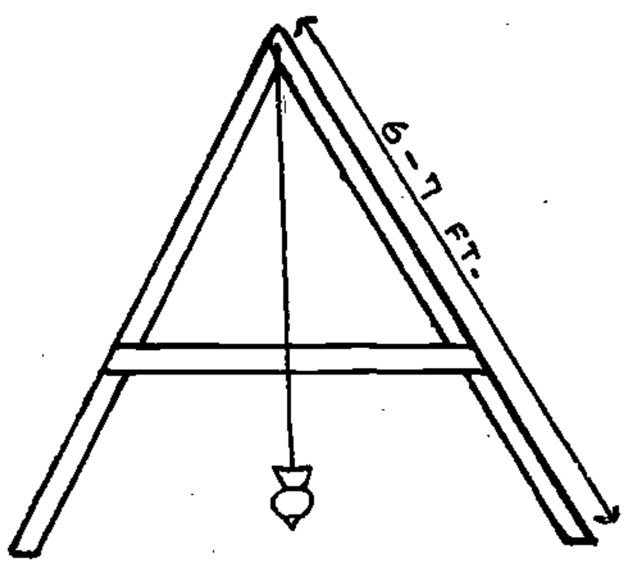
Note that all 4 methods act to shorten slope length and therefore decrease water flow volume and velocity. They not only fight erosion but increase water intake by soil as well; this will boost crop yields in a dry year.

All 4 methods also involve being able to mark out contour lines, so let's talk about that.

HOW TO LAY OUT CONTOUR LINES

There are several easy-to-make devices for laying out contour lines with the needed accuracy, but the A-frame is one of the best and easiest to make.

How to Build & Calibrate an A-Frame



A. Build the A-frame as above using either lumber (1 x 2's or 2 x 2's) or poles cut from brush. Nails or twine can be used to hold it together. The cross-arm is placed about half-way up. The string with end weight should be hung from a nail placed midway in the juncture where the 2 legs meet.

B. Calibration: To find the level mark on the cross-arm, choose a semi-level spot of ground and pound a couple 6-8" stakes halfway into the soil at a distance equal to the spread of the A-frame's legs. Place the A-frame on the stakes and make a pencil mark where the plumb-line comes to rest. Then reverse the legs and make a 2nd mark. The true level mark should be halfway in-between. To double check your calibration, adjust the stakes so that the plumb-line rests on the level mark; then reverse the A-frame, and if the plumb-line returns to the level mark, your calibration is OK.

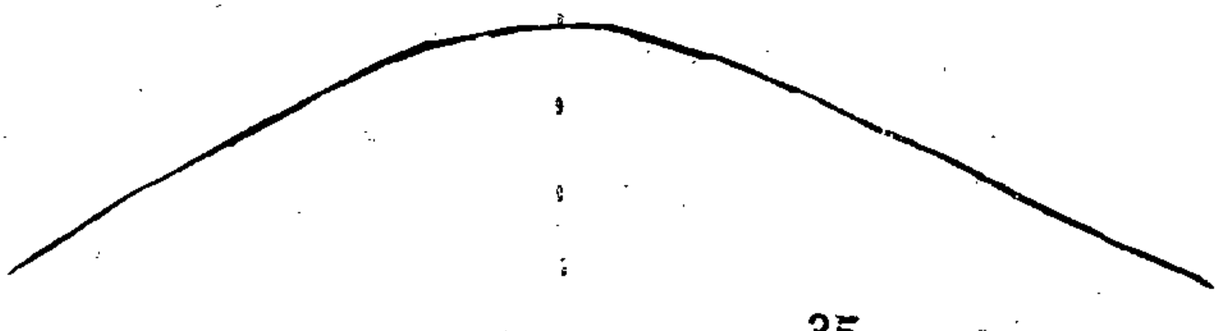
C. Using a level instead of a plumb-line: You can use a string level or small carpenter's level instead of the plumb-line; it's quicker. Before tying the level to the center of the cross-arm, make sure the A-frame legs are resting on level ground (i.e. the plumb-line should indicate level). You may have to whittle away at the cross-arm to get the level positioned so that the bubble rests between the 2 cross hairs.

How to Lay Out Contour Ditch-Banks with an A-Frame

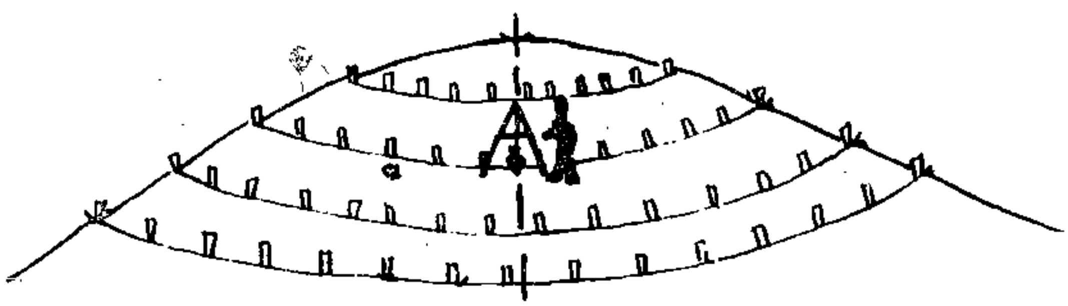
The contour ditch-bank system (ditch & barrier) can be easily layed out with an A-frame. Here's how:

1. Measure the Field's Slope: The spacing of the ditches depends on the slope. Determine the slope and then use the table on p.153 to find the correct spacing.

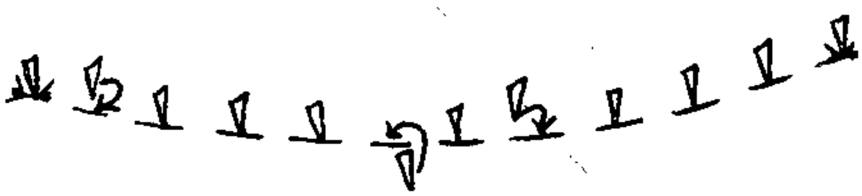
2. Stake Out the Ditch Intervals: Start at the top of the field and proceed straight downslope the distance indicated in the table. Suppose the slope is 30%; the interval between ditches would be 19' 8", so the first ditch would be placed 19' 8" downslope from the top. Place a stake to mark the first ditch and continue downhill marking the location of the other ditches. If the slope noticeably changes, you should measure the variations and adjust the ditch spacings according to the table.



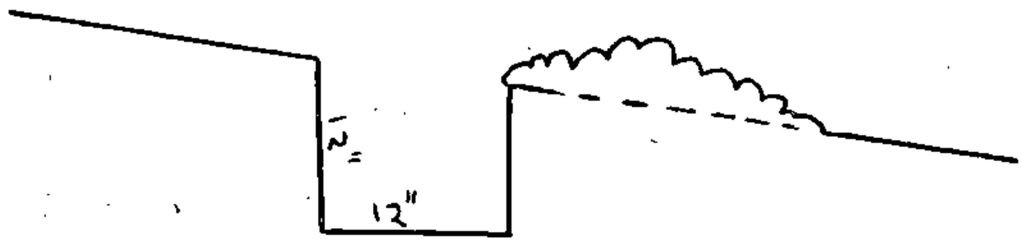
3. <u>Mark Out the Contour Ditch Lines with Stakes</u>: You'll need lots of stakes, since they'll be spaced at intervals equal to the A-frame's leg span. Begin at the top or the bottom ditch location and place one of the A-frame legs next to the master stake. Move the other leg up or downhill til the plumb-line reads level and pound in a stake at that point. You've just started a contour line. Now move the A-frame so that the leg that rested next to the first master stake now rests next to the 2nd stake; move the stake-less leg up and down til the plumb-line marks level and pound in a third stake flush with that leg. Continue across the field repeating the process til you reach the end. Do the same for the other ditch locations. You can save stakes along the way by taking out every other stake once a contour line is well established and using them farther along.



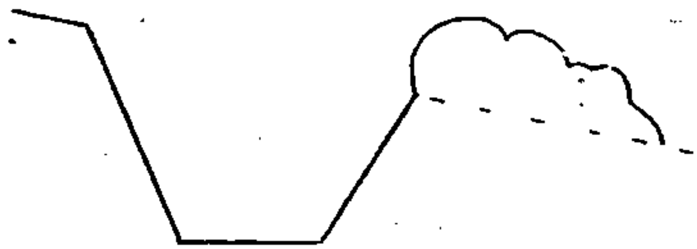
4. <u>Even Out Irregularities</u>: You don't want to end up with ditches full of zigs and zags, so try to smooth out any ragged portions by slightly altering the stakes.



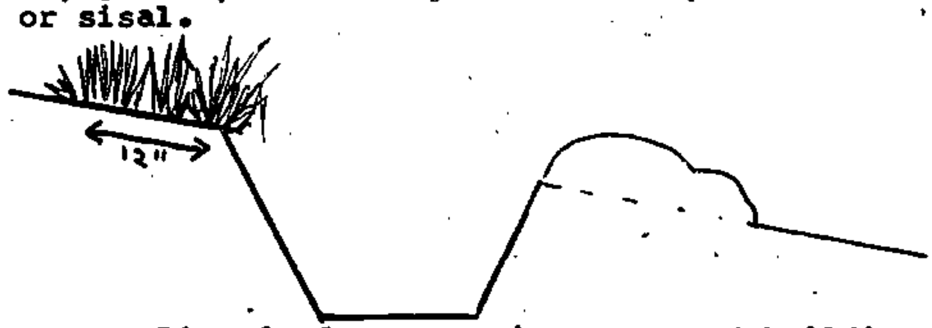
5. <u>Digging the Ditches</u>: Begin by tracing out the ditch line with a hoe or animal drawn wooden plow to give you a guideline. A plow will save some digging. Begin by making the ditch 12" (30 cms.) wide and 12" deep like so:



To prevent the ditches from eroding, the sides should then be tapered like so:



A live barrier (or use rocks) should be installed immediately above the uphill side of the ditch to prevent soil from filling it in. A live barrier should be about 12" (30 cms.) wide; a close growing grass like elephant, guinea, or jaragua works great; so does pineapple or sisal.



6. <u>Dikes or no Dikes?</u>: Some experts recommend building dikes every 5 meters (16') in the ditches to prevent excessive flow in the ditches. Others feel flow won't be excessive if the ditches don't slope more than 1%.

7. Making a Grassed Waterway: It's unlikely that the ditches won't have runoff on the ends. The runoff water can do lots of damage unless it runs down an erosion-proof grassed waterway. Dense, semi-short grasses like kikuyu, centipede, carpet, and Bermuda work well if you can keep them from spreading into the field.

Remember that crops are planted on the contour using the ditches as guidelines. It's a very effective system, especially if the crops are grown on ridges or hilled up during the growing season to provide further erosion barriers. Always recalibrate an A-Frame on each new occasion you use it.

How to Build a 1% Slope into an A-Frame

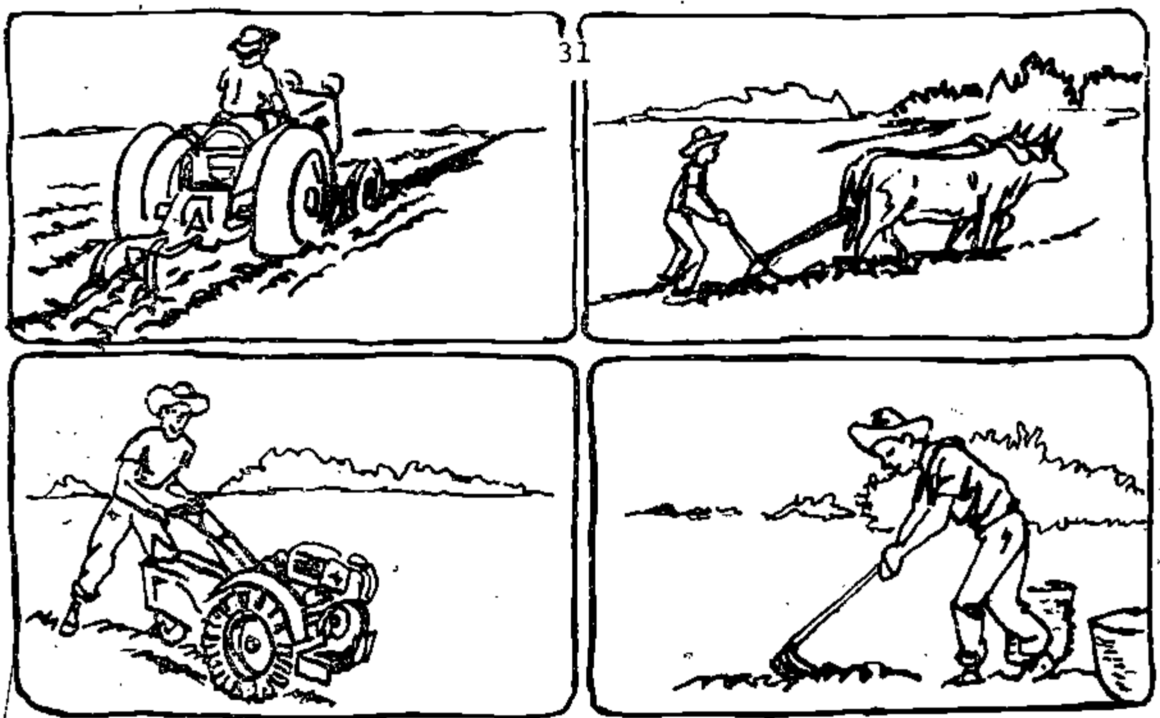
Many bulletins recommend that the contour ditches have a ½-1% slope to facilitate water movement so the ditches don't overflow. Here's how to build in a 1% slope (don't go over that):

1. Place the A-frame on a level surface so the plumb-line rests on the level mark. Raise one leg up a distance equal to 1% of the leg-span (i.e. if legs are 72" apart, 1% would equal about 3/4"). Make a mark where the plumb-line rests, and draw a short arrow from the mark pointing toward the unraised leg.

2. Return the A-frame to level and raise the other leg the same distance. Make another mark where the plumb-line rests, and draw another arrow pointing toward the unraised leg.

Using the 1% Slope A-Frame: The arrows refer to the direction in which the ditch will run downhill at 1% when the plumb-line rests on the mark adjacent to it. When laying out a ditch line across the field always use the same mark from start to finish. Some bulletins recommend running half the ditches one way and half the other to avoid overloading one waterway.

What about an A-frame with carpenter's level: Best way to build a slope into it is to make one leg shorter than the other by an amount equal to ½-1% of the leg span. Draw an arrow on the cross-bar pointing toward the longer leg; that's the direction in which the ditch will gently slope downhill.



PART III

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 and has 4 purposes:

1. To break up clods and loosen the soil to favor seed germination, seedling emergence, and root growth.
2. To chop up and/or bury the previous crop's residues so they don't interfere with the new crop.
3. To control weeds.
4. To shape the kind of seedbed most suitable for the particular soil, climate, and crop (i.e. raised beds, ridges, flat beds, etc.).

SOME COMMON TILLAGE EQUIPMENT

Moldboard Plow: Depending on size and soil conditions, it penetrates 6-10" and inverts the furrow slice it cuts through which makes it very effective for burying weeds and residues. Both animal drawn and tractor drawn models are used. It's used for the initial tillage operation, though bulky residues like corn stalks have to be cut up with a disk harrow first.

<u>Disk Plow</u>: Better suited than the moldboard to hard, clayey, or sticky ground but doesn't bury residues as effectively; handles rocky ground well; comes in tractor and animal drawn models.

<u>Wooden Plow</u>: Designs go back many centuries; some have a metal tip; animal drawn. The wooden plow doesn't invert the soil or bury residues but basically makes grooves through the soil; effectiveness depends a lot on soil type and moisture content.

<u>Disk Harrow</u>: Usually used after plowing to smooth and pulverize the soil; also used to chop up coarse residues before plowing. Models having scalloped disks (cutaway disks) cut crop residues better and penetrate deeper. Large, heavy duty versions (often called Rome plows) can sometimes substitute for plowing. Animal and tractor drawn disk harrows are available. Also used to kill weeds immediately before planting.

<u>Rototillers</u>: They come in self-powered and tractor-drawn (and powered) models and thoroughly pulverize the soil and handle crop residues; power requirement is high; heavy duty models can be used for a once-over complete tillage job.

<u>Hand Implements</u>: The hoe, shovel, turning fork, and rake do a highly effective job on small areas; by using a <u>double-digging</u> system (see p.34), you can even loosen the subsoil.

<u>A Quickie Way to Estimate the Amount of Land that can be Worked by Farm Equipment in a Day</u>

$$\text{Acres per Hour} = \frac{\text{Speed (in m.p.h.)}^{*1} \times \text{Width of Implement (in Ft.)}}{10}$$

$$\text{Hectares per Hour} = \frac{\text{Speed (kms./hr.)} \times \text{Width (in meters)}}{12}$$

<u>Example</u>: How many acres/hr. can be plowed by a tractor pulling a 3 disk plow with a 42" cut at 4 m.p.h?

$$\text{Acres/hr.} = \frac{4 \times 3\frac{1}{2}}{10} = 1.4 \text{ acres per hour}$$

The formula includes a 20% time allowance for turning at row ends.

---

*1. 88 ft. per minute = 1 m.p.h.; 55 ft. per minute or 17 meters per minute = 1 km. per hour.

THE ABUSES OF TILLAGE AND HOW TO AVOID THEM

Tillage can either enhance or destroy good soil tilth. Sure, plowing and harrowing break up clods and loosen up the topsoil, but the stirring and shearing action stimulate microbial breakdown of beneficial organic matter and may also pulverize the soil too much. Machinery, animal, and foot traffic compact soil under clayey and wet conditions.

The 2 implements most likely to harm tilth are the disk harrow and the rototiller; most farmers overdo it with the disk harrow by making repeated passes to suppress weeds or smooth the soil. Harrowing kills one stand of weeds but encourages another by bringing more weed seeds closer to the surface where they can germinate (the supply of weed seeds is inexhaustible). It's very easy to over-pulverize the soil with a roto-tiller.

The Ideal Seedbed: The only part of the seedbed that needs to be reasonably clod free is the narrow row zone where the seeds are planted. Your're better off keeping the spaces between the rows in a less worked, semi-cloddy condition it'll discourage weed germination and help maintain tilth.

In the past 15 years, minimum tillage systems like plowing and planting in one operation have gained favor in the States and Europe; one big side benefit is lowered machinery costs.

MAKING THE RIGHT SEEDBED FOR THE CROP, SOIL, AND CLIMATE

Seedbed Fineness

It's the type of seed that mainly determines how fine the row zone soil needs to be for good germination.

Small vs. Large Seeds: Large seeds have more power than small ones, and many can handle a fairly rough seedbed. Small seeds (i.e. cabbage, eggplant, turnip, etc.) are more delicate and need a finer seedbed for 2 reasons: 1. They don't have the strength to handle clods; 2. They require very shallow planting (1/4-1/2") and cloddy soil doesn't allow this precision.

Monocots vs. Dicots:*1 Monocot seedlings (corn, sorghum, rice, wheat, oats, grasses, onions, and garlic) break through the soil in the shape of a spike which lessens the need for a fine seedbed. Dicots (beans, peas, peanuts, and nearly all vegies) have much less clod handling power since they don't emerge as spikes. Large seed dicots don't need as fine a seedbed as small seed ones.

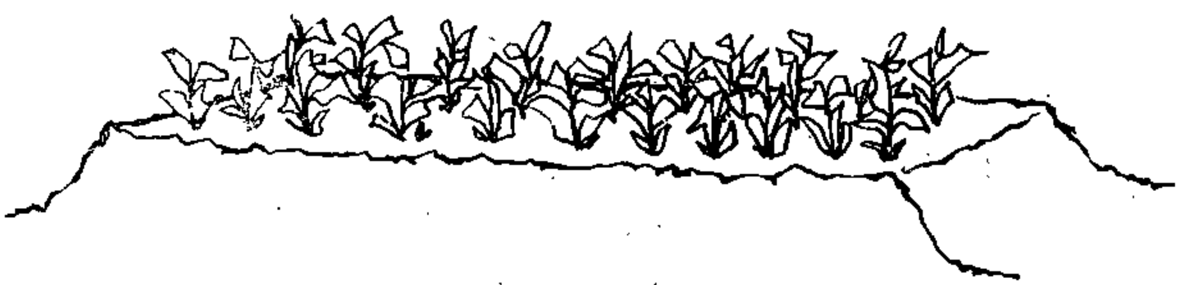
*1. Monocots have one cotyledon (seed leaf) and long narrow leaves with the veins running parallel the long way. Dicots have 2 seedleaves and broader leaves with veins in a feather type (pinnate) pattern.

Seedbed Shape

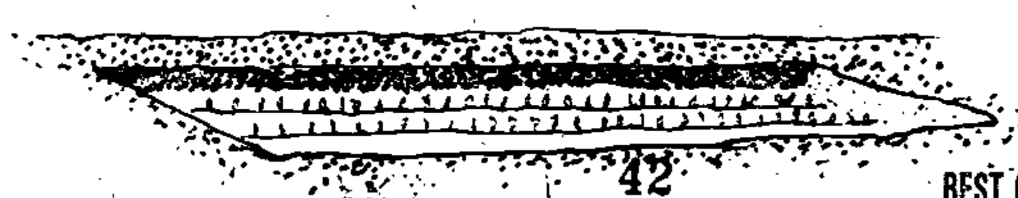
The ideal seedbed shape varies more with the climate and soil than with the crop. The common ones are:

FLAT SEEDBEDS: Used where soil moisture is adequate for crop growth and there are no drainage problems. It's common for corn, sorghum, and beans to be flat planted and then hilled up with soil as the season progresses.

RAISED SEEDBEDS: In areas of high rainfall and/or poor drainage, crops are usually planted on raised up beds or ridges to keep them from getting "wet feet". Raised beds are essential when crops are furrow irrigated. They're especially suited for vegie growing, since they keep the soil looser and make for less bending over. Soil-borne disease problems are less likely too. They can be used on sandy soils or under low rainfall conditions, but some type of mulching (see p. 67) is needed to cut moisture losses. You can also vary the height of the beds to control moisture retention (low beds for the dry season, high ones during the wet).



SUNKEN SEEDBEDS: Under low rainfall or sandy soil conditions, crops can be planted in slightly sunken beds or in the bottom of furrows where moisture is higher. Under these conditions, shallow rooted crops like onions with frequent watering needs are grown in shallow basins a couple inches below normal soil level. Field crops like corn can be sown in the furrow bottom, and then soil from the ridges is thrown into the seed row for weed control.



A WORD OF ADVICE: You'll find that local farmers have plenty of seedbed savvy, so beware of tampering with time-tested methods without first considering all the angles.

SOME HANDY SEEDBED SKILLS

How to Double Dig

Double digging is a great way to deep till small areas of compacted soil, since it enables you to loosen up some of the denser subsoil too. It'll benefit deep-rooted crops like tomatoes, eggplant, pepper, beans, and squash more than shallow growing crops like cabbage, radish, onions, garlic, and lettuce. You can double dig with just a shovel but a turning fork helps. Here's how. Doing it is the easiest way to understand. Get a shovel and follow these instructions on a 4 ft. x 4 ft. plot.

1. Divide the plot in half and mark the centerline. Start by digging a 2 ft. wide trench down to the depth of the shovel blade, running from one corner of the plot to the middle. Pile the soil just outside the plot and near the centerline (it'll be used to fill in the final trench).
2. If available, spread an inch or two layer of compost or manure over the undug portion of the plot.
3. Use the shovel or a turning fork (better) to loosen up (not invert) the soil in the trench bottom.
4. Push into the trench bottom the compost or manure that's on top of the next 2 ft. strip and then work it into the loosened subsoil.
5. Dig the next 2 ft. strip and invert the soil into the first trench to fill it up. Then treat the 2nd strip as per steps 3 and 4.
6. Continue on around the entire plot; the final trench will be adjacent to the first one but on the other side of the centerline; it's filled with the soil you dumped outside the plot in step 1.

The compost and manure help condition and enrich the subsoil. Try to avoid mixing the subsoil with the topsoil.

How to Cope with Soil Crusting Problems

Some soils high in clay or silt and in poor tilth tend to form a cement like crust at the surface after rain or watering; it can seriously affect seedling emergence, especially the blunt dicot seedlings (see p.32). Using a post-planting mulch over the seed row helps a lot. It absorbs raindrop splash and keeps the soil surface moist*1

*1. A healthy soil organic matter content is the best defense against crusting; compost and manure are a big help.

and less crusty. A "grow through" mulch like sawdust or rice hulls is best. Straw or grass can be used but if not removed as soon as seedlings start emerging, they'll quickly become leggy and prone to damping-off disease.

How to Make Up a Seedbox Soil Mix

Straight soil by itself just doesn't cut it as a planting medium for seedboxes. When confined in a shallow container, it's usually too poorly drained - gravity isn't strong enough to pull the excess moisture out (see p.19). Here are a few recipes for seedbox soil mixes used for growing transplants: (all mixes except #4 need heat or formaldehyde sterilization to prevent damping off disease).

1. 1:1:1 Sand-Soil-Compost. Modify the ratio to suit the soil you're using (if already sandy, use less sand).

2. A 2:1 rice hulls:soil mix. One advantage is it's light weight, but it may dry out quickly.

3. A 1:3 sand-compost mix. Rotted coconut husk fibers run through a 1/4" mesh screen make a great compost.

4. You can make an excellent mix called Peatlite if sphagnum peatmoss and vermiculite (made from heat popped mica) are available at a reasonable price:

   2 gals. sphagnum peatmoss (shredded)

   2 gals. horticultural vermiculite (#2 grade - semi-coarse)

   1½ oz. dolomitic limestone (contains both calcium and magnesium); 1½ oz. = 2½ tbs.

   2 teaspoonfuls*1 of superphosphate (0-20-0)

   4 tablespoons*1 (1/4 cup) 5-10-5 fertilizer*2 or equivalent.

The mix contains enough nutrients for 6 weeks (should be plenty of time) except maybe N *3.

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*1. Refers to level teaspoonfuls and tablespoonfuls; 1 level tsp. = 5 c.c.; 1 level tbs. = 15 c.c.

*2. Use a 1:2:1 ratio fertilizer if possible; 4 tbs. 5-10-5 = 5 tsps. of 12-24-12. A 1:2:2 fertilizer like 10-20-20 is more likely to cause burning unless you cut the rate back a third or so.

*3. If plants start to yellow from N deficiency (due to leaching losses), water 'em with a solution of 1 tbs. ammonium sulfate (1½ tsps. urea) per gal. of water; wash off leaves with plain water afterwards; one application should do it.

PART IV

SOME IMPORTANT SOIL FERTILITY BASICS

For most PCV's, fertilizer use is one of the more esoteric aspects of the ag scene. How and when do you apply them? How much and what kind? What about the chemical vs. organic controversy? We'll try to cover it all in the next few chapters, but first on to some important soil fertility basics.

HOW PLANTS GROW

Plants grow by enlarging their cells and developing new ones at their shoot and root tips. Growth requires sugars and proteins. Sugars are made in the green cells by photosynthesis when carbon dioxide from the air combines with water from the soil with the aid of sunlight and chlorophyll (the green pigment in plants).

Sugars are used for energy and to make cellulose (for cell walls) and starch (food storage). Proteins are formed by combining sugar and nitrogen and are used to make protoplasm (a vital part of cell fluid).

Role of the Plant Nutrients: The plant mineral nutrients are supplied by the soil and fertilizers; they're absorbed through the root hairs (tiny delicate protrusions from the root surface) in the form of ions (molecules with a plus or minus charge). Some, like potassium and magnesium, are needed for sugar formation, while nitrogen is an essential ingredient of protein.

AVAILABLE vs. UNAVAILABLE FORMS OF NUTRIENTS

Aside from water, oxygen, and CO_2, plants need some 14 other 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. Only about 1-2% of a soil's potassium is actually available to plants; most of the other 98-99% is tied up as part of rock fragments and clay particles and is very slowly released by weathering; some potassium is temporarily trapped between the plate-like units that make up clay particles.

Likewise, only about 1-2% of a soil's nitrogen is readily usable by plants. The rest is in the organic form which is unavailable until it's been mineralized into ammonium or nitrate by soil microbes (see p. 7).

The same goes for each of the other nutrients in varying degrees, depending on soil conditions. Soil pH (acidity or alkalinity) has a big effect on nutrient availability.

THE NUTRIENT HOLDING ABILITY OF A SOIL: Why it's Important

Some soils are much more prone to losing nutrients by leaching (downward movement of water) than others; leaching losses vary with a soil's texture and negative charge. Sandy soils are very susceptible to leaching losses because water passes through them quickly, and they have a low negative charge due to their lack of clay and humus particles (see p. 3). Even clayey soils vary a lot in leaching potential since clay type and humus content determine the amount of negative charge. Leaching also varies directly with the amount of rainfall.

How Negative Charge Helps Hold Nutrients

Remember that the available forms of the nutrients exist as ions (molecules with a plus or minus charge). That means that the plus (+) charged ions (called cations) such as K^+ (potassium), Ca^{++} (calcium), and Mg^{++} (magnesium) are attracted and held to the negatively charged clay and humus particles; this helps keep them from leaching. Just like a magnet.

The negatively charged nutrient ions (called anions) like NO_3^- (nitrate nitrogen) and $SO_4^=$ (sulfate) aren't so lucky. Since like charges repel, they're not held by the clay and humus particles and float around in the soil water. That's why negatively charged nutrients are much more easily lost by leaching than plus charged ones.

Here's some common plant nutrients and their leaching susceptibility:

+ 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^{++})	
Magnesium (Mg^{++})	(leaching losses of K can be a problem on sandy soils or under heavy rainfall)

What about Phosphorus?: It's an exception; although it's available forms have a minus charge, it hardly moves at all in the soil since it easily forms insoluble compounds with iron, aluminum, and calcium. Sure, it keeps phosphorus from leaching, but also keeps it from plants. This "tie-up" is called phosphorus fixation and can be a serious problem on many soils. How you apply fertilizer phosphorus makes a big difference in how much gets used (we'll get into that later). DON'T confuse P fixation with nitrogen fixation (the conversion of atmospheric N into usable forms by Rhizobia bacteria that form nodules on the roots of legumes; see p. 7).

The Exchange Capacity of a Soil (Only the Soil's Lab Knows for sure)

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.

The C.E.C. depends on the clay and humus content of the soil, since they're the only two components with a minus charge. Soils with a low C.E.C. have poor nutrient holding ability. Even soils with the same texture can vary greatly in C.E.C. due to differences in humus content and the type of clay they contain. Compare the variation in C.E.C. between humus and clay types:

	C.E.C.
Humus	150-200
Common temperate type clays	15-100
Common tropical clays*1	2-15

The table on the next page shows the great variation in exchange capacity among soils of the same texture.

*1. Remember that both temperate and tropical clay types are found in the tropics and subtropics! See p. 3.

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 relative comparison that counts. (If you're familiar with chemistry, the C.E.C. is measured in terms of milli-equivalents of cations per 100 grams of soil).

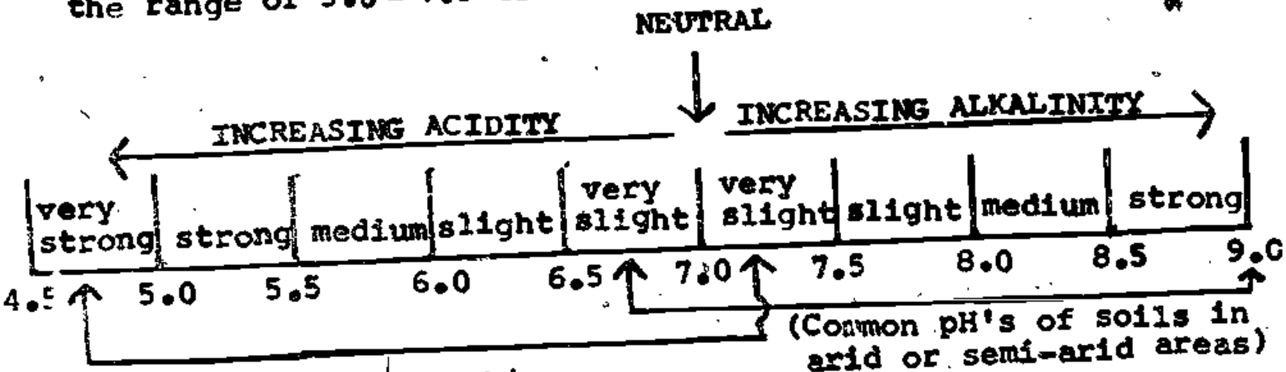
Some Needed Clarification: Although nutrient cations like potassium are held by clay and humus particles, they're *still available* to plant roots. Another point is that despite the soils negative charge, there's still some *leaching* of plus charged nutrients; they can get bumped off the clay and humus particles by hydrogen ions (H^+) or by each other (that's part of the meaning of cation *exchange* capacity).

Unless you're an ag science teacher, don't spend a lot of time trying to get all this down pat. Just remember that some nutrients leach more readily than others; that sandy soils have more leaching than clayey soils (especially of minus charged nutrients like *nitrate*); that the higher the C.E.C., the lower the leaching losses (especially of the plus charged nutrients).

You can greatly cut leaching losses of fertilizer *nitrogen* by knowing when and how often to apply it; we'll get to that farther on.

SOIL pH AND HOW IT AFFECTS CROP 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 (max. alkalinity), but most soils fall in the range of 5.0 - 7.5 or so with extremes from 4.0 to 9.0.



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

An important point!: The pH scale is logarithmic, meaning 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 a soil with a pH of 6.0. 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. A pH of 3.9 is 1000 times more acid than a pH of 6.9.

Why Do Soils Vary in pH?

Climate, amount of leaching, parent rock, and farming practices all affect soil pH.

1. CLIMATE & LEACHING: As the chart on the previous page points out, soils of wet climates are likely to be on the acid side. That's because a good deal of calcium and magnesium (the principal bases in the soil) have been leached out over time by rainfall. It's a slow process, since these two bases have a plus charge and are held by clay and humus particles. However, the acid forming H^+ ions produced by the breakdown of organic matter and acid rocks can bump the adsorbed (adhered) calcium and magnesium off the clay and humus particles back into the soil water where they can be leached. As H^+ ions gradually replace the bases on the clay and humus, the soil becomes more acid.

   In contrast to humid region soils, those of arid or semi-arid regions are likely to be alkaline or only slightly acid. That's because there's less leaching under low rainfall so calcium and magnesium levels are higher.

   Dry region soils aren't always basic, since parent rock and farming practices can modify the influence of climate. Wet region soils aren't always acid, either, but they tend to be.

2. PARENT ROCK: Soils formed from basic rocks like limestone and basalt tend to be less acid (or more basic) than those formed from acidic rocks like granite and sandstone; however, even soils formed from limestone may be acid if leaching has been intense.

3. FARMING PRACTICES: Liming the soil will lessen acidity (raise the pH). Manure, most composts, and many chemical fertilizers will increase soil acidity if used over a period of years.

Why Worry about pH Anyway?

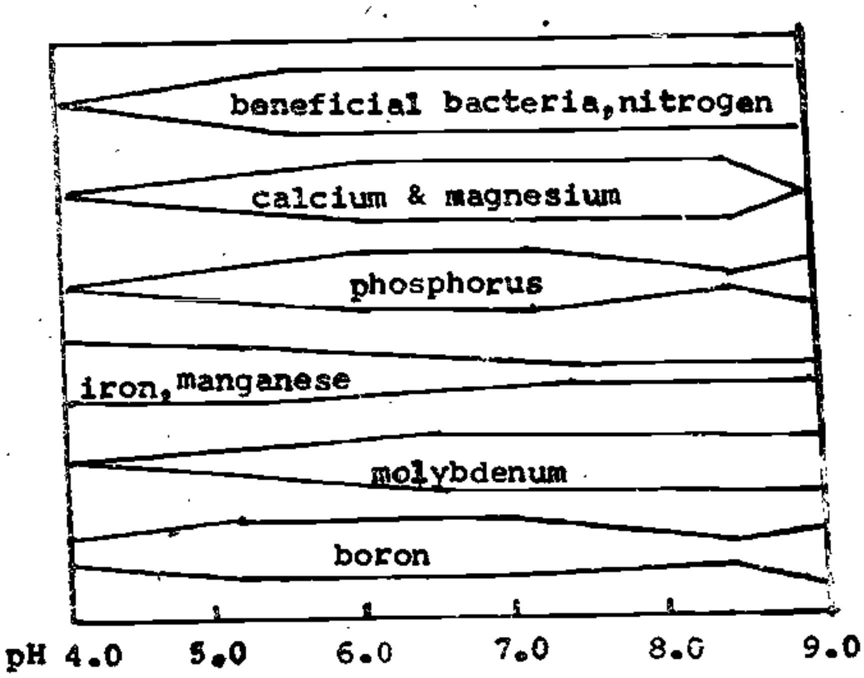
Soil pH can have a big effect on crop yields. Most crops grow best within a pH range of 5.5-7.5 (moderately acid to slightly alkaline or basic); a pH of around 6.3 or so is ideal for most. Some crops like sweetpotatoes, potatoes, coffee, pineapple, watermelon, and rice are more tolerant of greater acidity.

How Soil pH Affects Crop Yields

1. The tie-up of phosphorus is greatly affected by pH. P is most available to plants within a pH range of about 6.0-7.0. As pH falls below 6.0, increasing amounts of P get tied up in insoluble compounds with iron, aluminum, and manganese. Above pH 7.0 P starts forming insoluble compounds with calcium and magnesium. Because calcium and magnesium exist in much larger quantities, they remain available.

2. Micronutrients: pH has a big effect on the availability of micronutrients (see p. 48). Except for molybdenum, the other micronutrients (iron, manganese, copper, zinc, and boron) become increasingly less available as acidity decreases and alkalinity increases. Iron and manganese are the most affected and can sometimes become deficient at pH's as low as 6.5.

   The chart below gives a good visual idea of the effect of pH on nutrient availability, etc.:



3. Very Acid Soils can be Toxic to Plants: Aluminum and manganese become more soluble as acidity increases and can actually become toxic to plant roots at pH's below 5.0-5.5 (varies with the soil).

4. Beneficial soil microbes: Most can't thrive in very acid soils, and this slows down the conversion of the unavailable organic forms of nitrogen, phosphorus, and sulfur to the available mineral (inorganic) form.

5. Salinity and Alkali Problems: Very high pH's (8.0 and up) usually indicate salinity and/or alkali problems. They're almost entirely confined to arid or semi-arid areas, especially in irrigated soils. Both sodium and other salts are toxic at high levels; We'll cover saline and alkali soil problems on pp. 143-149.

How Do You Measure Soil pH?

The soils lab determines pH as a routine part of soil testing. You can make fairly accurate readings right in the field using a color sensitive liquid indicator kit or a portable electric tester. Read the instructions carefully.

When measuring pH in the field, be sure to take separate readings for topsoil and subsoil - they're usually different. Very acid subsoils can prevent full root growth.

CAUTION! Portable soil pH test kits are handy for trouble-shooting soil pH problems, but they don't tell you how much lime is needed to treat excessively acid soils. That varies a lot with the soil's texture and exchange capacity. Only a reliable soil testing lab knows for sure. Overliming a soil can be worse than not liming at all. We'll cover liming in Part8 .

How Do You Change Soil pH?

Liming will lessen soil acidity and raise pH. Limestone (calcium carbonate), dolomitic limestone (combination of calcium & magnesium carbonates), and burned lime (calcium oxide) are common liming materials. Gypsum (calcium sulfate) and sulfur are commonly used to lower pH.

IMPORTANT FACTS ON THE PLANT NUTRIENTS

The plant nutrients fall into two broad groups: 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)

Macro- vs. Micronutrients

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 and likelihood of deficiency.

That doesn't mean that the secondary macronutrients or the micronutrients are any less essential; although their deficiencies aren't as common, they can have just as serious an effect on crop yields.

As shown below, the micronutrients are used in much smaller amounts than the macronutrients:

Amount of Nutrients Taken Up by a
100 Bushel Yield of Shelled Corn (5600 lbs.)

Macronutrients	Lbs.	Micronutrients	Lbs.
Nitrogen	157	Iron	4.2
Phosphorus (P_2O_5)	60	Manganese	1.0
Potassium (K_2O)	124	Zinc	0.30
Calcium	29	Copper	0.07
Magnesium	25	Boron	0.07
Sulfur	17	Molybdenum	0.0075

Tie-up of Added Fertilizer Phosphorus

Only about 5-20% of the fertilizer P you apply will be available to the crop. The rest becomes "fixed" (tied-up) as insoluble compounds. Not all this tied-up P is lost forever; depending on the soil, anywhere from a little to a lot will slowly become available to future crops; high and low soil pH's increase the amount and permanence of P fixation; the clay type is important too; some hydrous oxide clays of the tropics can tie-up 99%+ of the added P unless unbelievably high rates are applied.

Application Method is Vitally Important: The application method you use will largely determine how much of the added P gets tied up, especially when using small to medium amounts (that's all your farmer clients can afford) and working with high tie-up soils. See pp. 78-79.

Phosphorus Doesn't Leach

P is virtually immobile except in extremely sandy soils. Many farmers and PCV's place fertilizer P way too shallow, and very little ever gets to the roots. See p. 79.

POTASSIUM (K)

K promotes starch and sugar formation, root growth, disease resistance, stalk strength, and general plant vigor. Starch and sugar crops like sugarcane, potatoes, cassava (manioc, yuca), sweetpotatoes, and bananas have relatively high K needs. Corn, sorghum, rice, and other grasses are more efficient K extractors than most broadleaf crops.

Volcanic Soils Usually High in K: Most volcanic soils tend to have good K contents. Many Central American soils fall into this category and won't give economical responses to K except with starch and sugar crops or after years of heavy cropping. Only the soils lab can tell for sure.

Available vs. Unavailable K

Only about 1-2% of a soil's total K is in the available form (see p.37). Some soils have a high enough K tie-up ability to cause problems, but this is confined to a minority of temperate type clays.

Leaching Losses are Usually Minor

The available form of K has a plus charge so leaching losses aren't serious except on sandy soils or high rainfall conditions on low C.E.C. soils.

"Luxury Consumption": Plants have a tendency to take up more K than they need, especially if other nutrients aren't in balance. Some agronomists feel that this is definitely a problem with pasture grasses where high K can lower magnesium intake enough to cause deficiencies in both the crop and 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 raise soil pH (lessen acidity). It takes large amounts to raise pH compared to those needed for plant nutrition. Even very acid soils usually have enough calcium as far as plant needs, but soil pH may be too low for good growth. The available form of calcium has a plus charge and leaches slowly.

MAGNESIUM

Magnesium deficiencies are most likely to occur in sandy, acid soils (usually below pH 5.5). Like calcium, it's relatively resistant to leaching.

The Calcium-Magnesium Ratio: If there's too much Ca relative to Mg in the soil, some crops will develop Mg deficiencies even though the soil appears to have enough. This usually is more a problem on sandy soils with low exchange capacity where it's easy to upset the nutrient ratios. When liming a soil, it's a good idea to use dolomitic limestone (a 50-50 mix of calcium and magnesium carbonates).

Potassium Induced Mg Deficiencies: (see top of page)

SULFUR

Sulfur is needed for protein synthesis and by the Rhizobia bacteria that fix N for legumes. It forms part of several vitamins and is also used in oil formation.

Cabbage family (crucifer family) crops like cabbage, turnip, radish, mustard, broccoli, etc., and onions and asparagus have very high S requirements; tobacco, cotton, and legumes use a lot of S too.

Where to Suspect Deficiencies: They're not very common but most likely to occur in coarse textured soils under high rainfall where leaching has been high. Many volcanic soils tend to be low in S. Farmland near industrial areas usually receives enough S from the air. Continued use of low sulfur types of fertilizers may lead to deficiencies (see p. 76).

Leaching Losses of Sulfur: The available form of sulfur is the $SO_4^{=}$ ion which is readily leached, especially in sandy soils or under high rainfall. A good part of the soil's sulfur is in the organic form which microbes convert to the available mineral form. This is an important reservoir of sulfur, since organic S doesn't leach.

Work has shown that appreciable amounts of sulfur can be retained against leaching in subsoils high in tropical type clays; this sulfur is available once the roots reach it. (See pp. 3-4)

THE MICRONUTRIENTS

The micronutrients perform many vital functions but are needed in super small amounts (see table on p.43). The difference between toxic and deficient levels is often small. As little as 1 ounce of molybdenum per acre might cure a deficiency for several years, but 3-4 lbs. might severely injure plants. Boron is another touchy one.

Iron, manganese, copper, zinc. molybdenum, and boron are the important micronutrients; sodium and chlorine are sometimes included but are rarely deficient.

Prevalence of Deficiencies: They're much less common than macronutrient deficiencies but can be serious when they occur.

Where to Suspect Deficiencies

1. Highly leached, acid , sandy soils.
2. Peat soils.
3. Soil pH's above 7.0 (see p. 41).
4. Intensively cropped soils fertilized with macronutrients only.

Vegies, legumes, and tree crops are more subject to micronutrient deficiencies than grasses and grain crops; sorghum, however, is very sensitive to iron deficiencies.

Micronutrient Toxicities: Iron and manganese may become toxic to plants in very acid soils (below pH 5.0-5.5). Poor aeration and drainage increase severity.

Correcting Deficiencies or Toxicities

1. Adjusting pH: Molybdenum deficiencies can often be more effectively corrected by raising soil pH if very acid. Raising pH is about the only way to correct iron and manganese toxicities (aluminum too).

2. Soil applications of micronutrients: The effectiveness of soil applications varies; iron and manganese are very readily tied up when soil applied. Special chelated forms are much less subject to tie-up.

3. <u>Foliar Applications</u>: Since such small amounts are needed, spraying the plants is practical and also avoids soil tie-up problems. Usually, several applications are needed. In some cases, common <u>fungicides</u> like Maneb (contains manganese), Zineb (contains zinc), and Cupravit (contains copper) are used to supply micronutrients to vegie and orchard crops in conjunction with fungus disease control.

PART V

DETERMINING FERTILIZER NEEDS

The amount of nutrients different crops must absorb from the soil to reach a given yield is fairly well known. So why not just add what's needed?

1. You need to know what share of the nutrients your soil can supply.
2. A plant's ability to recover nutrients from applied fertilizer depends on:
   a. Type of crop.
   b. The particular soil's capacity to tie up different nutrients.
   c. Weather conditions (sunlight, rainfall, temperature), leaching losses, and soil physical factors like poor drainage and compaction; insect and disease problems too.

"Rose Fertilizer"? "Tomato Fertilizer"? No Way!: Think back to your typical Stateside garden shop. Remember those boxes of fertilizer labelled "TOMATO FERTILIZER", "ROSE FERTILIZER", etc? There's really no such thing. Sure, we know that starch and sugar crops have higher potassium needs than others, but your soil's K level might already be high enough so that little or none is needed. Soils vary so much in fertility that no one fertilizer could possibly be the right kind for all types of soils, even for one type of crop.

On a small garden plot, you can usually get away with being general; but when it comes to the larger scale commercial crops, your farmers shouldn't be wasting their money on fertilizers whose nutrient contents may be grossly inappropriate for their soil.

<u>So What's the Answer?</u>: Here are 5 basic methods that can give a fairly good idea of fertilizer needs on a particular soil:

1. Soil testing, preferably by a reliable soil lab rather than a do-it-yourself kit.
2. Plant tissue testing.
3. Fertilizer trials.
4. Spotting visual "hunger signs" in crops.
5. An educated "guestimate".

<u>Soil testing</u> is the most accurate but should be supplemented by one or more of the other methods for best results.

I. SOIL TESTING

Hopefully, your country has one or more soil testing labs run by the ministry of ag or private outfits; here's what you can expect from sending in soil samples:

a. Most labs routinely test for available P and K and measure soil pH and exchange capacity (see p. 38). Most usually don't test for available N, since results are often dubious (see below).

b. Many will be able to test for the secondary macronutrients (Ca, Mg, S) and some micronutrients. Tests for most of the micronutrients and sulfur are of varying reliability, depending on the sophistication of the equipment.

c. They'll usually be able to tell you how much lime your soil needs if it's overly acid; most can test the salinity and alkali hazard of the soil and irrigation water (most common in arid or semi-arid areas).

d. At the very least, the lab will give you an N-P-K application recommendation for the crop and maybe include other nutrients. The better labs will tailor the recommendation to more or less suit the particular farmer's capital and management situation (you supply this info on the sheet accompanying the sample).

Soil Tests Vary in Accuracy

As you've already guessed from the above, soil tests vary in reliability:

a. <u>Improper Sampling</u> is probably the biggest culprit. The half a pound or so of soil you send in may represent up to 15,000 TONS of soil and is supposed to be a composite sample made up of 10-20 sub-samples taken over an area that's similar in color, texture, topography, and past management (they all affect fertility). Many farmers and PCV's aren't taking samples correctly. We'll get to this below.

b. In order to make reasonably accurate fertilizer recommendations, the lab has to make numerous field and greenhouse trials on the soils involved to correlate test results with actual crop responses to fertilizers; some countries are way ahead of others in this.

c. Micronutrient tests aren't routinely run by most labs and they vary in accuracy. The test for available nitrogen is more of a guestimate, since the amount of N a soil releases from the organic form during a crop's growth depends on temperature and moisture conditions which affect microbial activity.

d. Even if tests were 100% accurate and you followed the results, the crop might still suffer from a deficiency due to excessively hot, cold, wet, or dry weather, etc. which can slow nutrient uptake.

Still, soil testing by a reliable lab is invaluable.

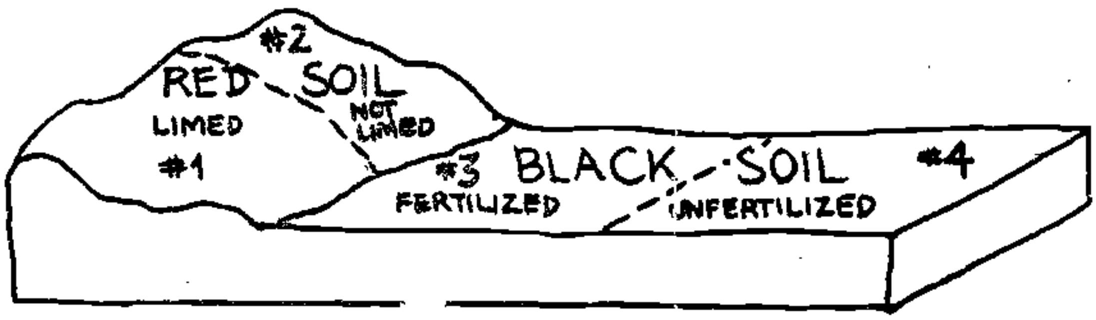
What about those Portable Soil Test Kits?: Those portable kits you see advertised in gardening magazines supposedly measure soil pH, N,P,K, and maybe other nutrients. Even the expensive ones are a poor substitute for lab testing. They're not nearly as accurate and the reagents don't keep well. You're much better off encouraging farmers to get used to sending in samples to an established soils lab.

HOW TO TAKE A SOIL SAMPLE

Proper sampling is the most crucial part of soil testing (given a good lab, that is). Before sampling, read over the soil lab's instructions (usually printed on the sampling box or on a separate sheet). Here's the general procedure:

1. Divide the land into sampling units: Start by drawing up a map of the land to be sampled and divide it according to soil color, texture, topography, and past management (fertilizer, liming, etc.); each sampling unit should be as uniform as possible in these combined characteristics (i.e. don't lump red soil and black soil or hill soil and flat soil in one sampling unit). Be sure to get the land's thorough fertilizer and liming history. The final map with numbered sampling units might look something like this: (see next page).

*1. In a recent Stateside training program, we tried out one popular kit that's supposed to measure NPK and pH; even the colors in the color charts varied from kit to kit due to cheap printing; the instructions have some bogus ag info too.



Most labs like you to limit a single sampling unit to no more than 10-15 acres (4-6 hectares); if you're working with small farmers, you're more likely to have pretty small units.

2. Taking the Samples:

a. If the farmer has 3 sampling units, he'll end up sending in 3 boxes of soil (about 1/2 lb. each) to the lab. Each sample is made up of 10-20 sub-samples taken randomly within the same sampling unit. Don't take sub-samples from fertilizer bands, under animal droppings, on headlands (row ends) or along a fence line.

b. Depth of sampling: Most labs want only topsoil samples (6-9" deep), though some ask for separate subsoil samples too; some want only 2" deep samples when sampling pasture land. Never mix topsoil with subsoil.

c. Taking a sub-sample: A shovel and machete work fine, though a soil auger is easier on hard ground. If using a shovel, make a 45° hole to the right depth, and then try to cut out a slice about an inch or two thick to the correct depth. Holding the face of the soil slice with one hand will keep it from crumbling apart. Trim down the width of the slice with the machete til it's a couple inches wide and dump it in a pail. Scrape off any surface litter before sampling.

During and after collecting the sub-samples, mix them thoroughly in the pail, and then take out enough soil to fill up the sampling box. Never mix soil from different sampling units! Don't oven dry wet samples; it'll cause a falsely high potassium reading. Air dry them instead. Make sure the pail you're using is thoroughly clean. A galvanized pail may make a zinc test invalid.

3. Fill Out the Information Sheet: It asks questions about soil slope and drainage, cropping history, crop to be grown, yield expected, and past applications of fertilizer and lime on each sampling unit.

When to Take Samples: Send them in at least 6 weeks or more before you need the results; in areas with a well defined cropping season, farmers tend to wait until a week or two before planting; the soils lab can't cope with the rush.

How Often is Testing Needed?: Under low to moderate rates of fertilizer use, the field should be sampled about once every 3-4 years. Most of your farmers can't afford enough fertilizer to markedly affect the soil's fertility on a year to year basis; they should be concentrating on feeding the crop rather than building up the soil.

II. PLANT TISSUE TESTS

The crop itself can be tissue tested in the field for N-P-K levels in the plant sap; kits cost about $20-$40, but some of the reagents need to be replaced every year.

Tissue tests are best used to supplement soil test data, but the results can be tricky to interpret; sometimes plant sap nutrient levels aren't related to those in the soil, since weather extremes, insects, and diseases affect uptake. Deficiencies of one nutrient like nitrogen can stunt crop growth and cause a "pile up" of P and K in the sap, giving a falsely high reading.

Total Plant Analysis: Some labs can run a total nutrient analysis of plant leaves with a spectrograph, but it may cost $10-$15.

One advantage of tissue testing is that it may be possible to correct diagnosed deficiencies (especially N) by adding more fertilizer.

CAUTION: The tests are geared to much higher yield levels than most of your farmers can reasonably shoot for; their management and affordable fertilizer levels may show up as semi-deficient N-P-K tissue test results, despite following soil test recommendations; yet the yield increase attained by these moderate fertilizer rates may be the most profitable on a return-per-dollar basis. (See p. 88).

III. FERTILIZER TRIALS

Properly conducted fertilizer trials are very helpful; here's 2 kinds:

Test Strips: Run several test strips through the field to try a couple different rates or nutrient combinations; you'll need two or more test strips (about 3-4 rows wide each) in different parts of the field for the same treatment to cut down the influence of field variation (it should be the same type of soil visually and past management-wise). Don't rely on one year's results alone since weather and pests can influence yields.

Formal Trials: The different treatments are randomized and replicated as small plots within one bloc; each plot is usually only a few rows wide and several meters long; plot size, plant population, and fertilizer rates are carefully measured as well as yield differences, and they're run over 2-3 years. This is the only kind of trial that is statistically significant. It's tedious work.

Trials vs. Demonstrations

Trials are used to help determine fertilizer rates. Demonstrations are used to show farmers the benefits of appropriate rates. The simplest and most effective demo uses two plots, one with and the other w/o fertilizer; you should soil test first and/or use trial info to determine rates.

Some guidelines:

1. Don't try to use a trial as a demonstration; results may look confusing and contradictory to farmers.

2. Don't set up a demo plot without basing fertilizer rates on soil tests and/or other data.

3. Do involve the farmer whose land is being used. Don't run it on your own land. If you do all the work yourself, farmers are likely to view the demo as some complicated and mysterious American ritual beyond their abilities.

4. When setting up a trial or demo, be sure to control serious limiting factors like insects which could wipe out or mask fertilizer response.

5. Fertilizer demos give the most spectacular visual response on poorer land; don't use a field that's been heavily fertilized in the past, yet don't locate it on atypically poor land.

IV. SPOTTING VISUAL "HUNGER SIGNS"

Severe nutrient deficiencies often cause characteristic changes in plant appearance such as size and leaf color. Spotting hunger signs can be a useful tool, but be aware of several drawbacks:

1. Some hunger signs are easily confused with each-other or with disease and insect damage; if more than one nutrient is deficient at once, the hunger signs may be vague.
2. Hidden Hunger: A nutrient deficiency may be serious enough to cut yields by 30-60% without the appearance of hunger signs; in most cases, plants have to be really starving before showing hunger signs. The crop may look good during the growing season, yet hidden hunger can result in unnecessarily low yields.
3. It may be too late to correct deficiencies by the time hunger signs appear.

Learning the Hunger Signs: Hunger signs for common crops are described on pp. 155-59 . A picture is worth at least 1000 words, though, so try and get hold of a copy of:

> Hunger Signs in Crops, 4th ed., edited by H.W. Sprague. David McKay Co., New York. It's a great general reference on hunger signs and has numerous color plates.

V. AN EDUCATED GUESTIMATE

If no soil test info is available for the farmer's soil, you can make an educated guestimate based on:

1. Available soil test results from nearby farms with the same soil type, though past fertilizer applications can change results; fertilizer trial data on the same soil type can be used too.
2. An extension pamphlet on the crop with fertilizer recommendations for your zone (these vary in accuracy).
3. The particular crop's relative nutrient needs (p. 89).
4. A thorough examination of the soil for depth, drainage, tilth, slope; pH too if you can; these may limit fertilizer response.
5. Yield history and past management of the field.
6. The farmer's management ability and willingness to use complementary practices like improved seeds, insect control, etc.

We'll get into all this in Part VI.

PART VI

HOW TO USE
ORGANIC FERTILIZERS & SOIL CONDITIONERS

THE CHEMICAL vs. ORGANIC CONTROVERSY

Chemical (i.e. "synthetic" or "inorganic") fertilizers have come under fire, being accused of everything from "poisoning" the soil to producing less tasty and nutritious food. Should you encourage your farmers to forget about chemical fertilizers and use only organic ones (compost, manure, etc.)?

The "organic way" is basically very sound since organic matter (in the form of humus) is a fantastic soil improver (see p. 4). But over the years, some misleading and illusory claims have been tacked onto the organic approach. (The Complete Book of Composting, an epic 1000+ page tome that rivals War and Peace, even has a chapter titled "Compost and Mental Health")!

Let's take a look at the key issues:

1. Are Organic Fertilizers Better for the Soil than Chemical Fertilizers?

Chemical fertilizers supply only nutrients and exert no beneficial effects on soil physical condition; organic fertilizers do both.

2. Then Why not Forget about Chemical Fertilizers?

Compost and manure are relatively low-strength fertilizers (100 lbs. of 10-5-10 chemical fertilizer has about the same NPK content as one ton of average farm manure.) They need to be applied in large amounts (like 12-20 tons or more per acre yearly to make up for their low analysis and to supply enough humus to significantly improve soil physical condition. Except for relatively small areas, it's difficult for most farmers to obtain and apply these hefty quantities. Added to this is the problem of rapid organic matter breakdown, especially in the tropics, which often makes its benefits shortlived. Nearly all the successful projects that rely solely on organic fertilizers are confined either to small parcels or to cooler climates like Vermont, Oregon, the Guatemalan Highlands, etc.

The overwhelming verdict is that chemical fertilizers and organic soil improvers applied together are more effective than either alone. One study done at the Maryland Agric. Expt. Station showed a 20-33% yield increase when chemical fertilizers and organic matter were applied together, compared to applying double the amount of either alone.

2. Do Chemical Fertilizers Kill off Beneficial Soil Life?

Many organic enthusiasts claim that chemical fertilizers "poison" the soil and turn it into a sterile, lifeless medium incapable of producing good crop yields without continual chemical applications. Beneficial soil microbes (see p. 7) and earthworms thrive on organic matter, it's true, and their numbers will drop as organic matter declines. Once virgin ground (high in o.m.) is put under cropping, organic matter levels decline whether or not chemical fertilizers are used. It takes large and frequent additions of organic matter to maintain a good soil humus level. Evidence that chemical fertilizers harm earthworms is conflicting - lack of o.m. is much more a factor.

Chemical fertilizers themselves don't speed up the loss of organic matter but usually increase crop yields to well above those obtained if a virgin soil is first put under no-fertilizer cropping. Hydroponic and greenhouse cropping uses sterile artificial soil and chemical nutrient solutions, yet record yields are obtained. Still, natural outdoor soils usually need both organic matter and chemical fertilizers for best yields.

4. Are Organically Grown Crops More Tasty and Nutritious?

Numerous studies have shown no differences in protein or vitamin contents. Nearly all home-grown produce, whether organically or chemically grown, tastes better than the less fresh, supermarket fare. The vitamin content of a leafy vegie (esp. vitamin A) depends mainly on leaf exposure to sunlight. That's why leaf lettuce averages about 6 times higher in vitamin A than head lettuce.

Whether from chemical or organic sources, fertilizer nutrients usually help increase vitamin content. Plant roots can't distinguish between the two sources; that's because in order for an organic form of nutrient to be absorbed, it must be first converted into an inorganic (i.e. chemical) form. Plant roots end up taking in a nutrient in the same ionic form whether it comes from an organic or inorganic source.

ORGANIC FERTILIZERS AND SOIL CONDITIONERS

We'll cover manure, compost, other organic sources, green manure crops, earthworms, and mulching.

I. MANURE

Fertilizer Value

Animal manure is a great source of organic matter, but how about its fertilizer value? That depends a lot on the type of animal, quality of its diet, kind and amount of bedding used, and how the manure is stored and applied. Poultry and sheep manure usually have a higher nutrient value than horse, pig, or cow manure.

On the average, farm manure contains about 10 lbs. N, 5 lbs. P_2O_5, and 10 lbs. K_2O per ton along with various amounts of the other nutrients (this takes into account normal storage and handling losses which run about 25-50%). This works out to a 0.5-0.25-0.5 fertilizer formula (see p. 70). BUT only about 50% of the nitrogen, 20% of the phosphorus, and 50% of the potassium is readily available to plants during the first couple months since most is in the organic form and has to be mineralized by the soil microbes first. It does mean that farm manure has good residual fertilizer value even though it's very low strength compared to chemical fertilizers.

Here's a table that compares the relative N, P, and K contents of different animal manures; remember that actual values depend a lot on the diet, storage, and handling:

Type of Manure	N	P_2O_5	K_2O
Poultry	1.0%	0.8%	0.4%
Sheep	0.95%	0.35%	1.0%
Horse	0.7%	0.25%	0.55%
Cow	0.5%	0.2%	0.45%
Pig	0.5%	0.35%	0.4%
Rabbit	2.4%	1.4%	0.6%

Farm Manure is Low in Phosphorus: It tends to have too little available phosphorus in relation to N and K. If using it as the sole source of fertilizer, many experts suggest fortifying it with 50-60 lbs. of single superphosphate (0-20-0) per ton; it not only beefs up the P content, but reduces the loss of N as ammonia; usually it'll be much easier to apply P directly to the soil instead.

Amount of Manure Produced

It's a surprising amount per animal *if* you can collect it: (note that total dry matter is very similar)

Tons of Manure Produced Annually
Per 1000 lbs. Live Weight

Animal	(Fresh Wt.) Solids	Urine	(Fresh Wt.) Total	Total Dry matter
Horse	7.2 tons	1.8 tons	9 tons	2.0 tons
Poultry	4.2	0	4.2	2.14
Cow	9.5	4.0	13.5	1.9
Pig	9.1	6.1	15.2	2.0
Sheep	4.1	2.1	6.2	2.0

How to Store Manure

Store manure in piles with steep sides to shed water and good depth to reduce leaching losses by rain. It's far better to store it under a roof or in a covered pit.

Applying Manure

When: It's best applied a couple weeks to a few days before planting time. If applied too far in advance, some N may be lost by leaching. To avoid burning crops, fresh manure (as opposed to rotted manure which has less burning potential) should be applied a week or more in advance.

How: Manure should be plowed, disked, or hoed under soon after application; a delay of just one day may result in a 25% N loss as ammonia gas (50% in 2 days).

How Much to Apply?: Rates of 10-15 tons/acre (22,000-33,000 kgs./hectare) are a general figure, but limit poultry and sheep manure to 4-5 tons/acre (9000-11,000 kgs./ha.). This works out to about 0.5-0.7 lbs./sq. foot (2.5-3.5 kgs./sq. meter) except for poultry and sheep manure (0.2-0.25 lbs./sq. foot or about 1 kg./sq. meter). You can probably double these rates, but you're better off using a moderate rate over a larger area rather than a high rate on a small area (if quantities are limited). Large amounts of fresh manure may burn roots and seeds (esp. pig, poultry, sheep). Very strawy manure may cause a temporary N deficiency unless supplemental N is added to the soil (see p.44).

Some Other Methods & Guidelines for Using Manure

1. You can mix pig or poultry manure, etc. 50-50 with water and use it to side-dress growing crops (like once every week or two), but it may burn shallow rooted crops (cabbage, lettuce, onions, etc.).

2. DON'T use pig manure on vegies whose edible parts touch the soil (onions, cucumbers, carrots, lettuce, etc.); many swine parasites can be passed on to humans this way. Don't use human manure on any crop for the same reason (even if composted).

3. Cattle manure from commercial feedlots (confined, concentrate feeding) is likely to have an overly high salt content and may easily injure crops (esp. seeds and seedlings).

4. Use the strip or slot method if manure is scarce, confining it to the crop row or hill. Unless well rotted, avoid contact with seeds or seedling roots.

5. Even high rates of manure won't always satisfy a crop's entire NPK needs so some supplemental chemical fertilizer (or high analysis organic source like cottonseed meal) may be needed. Manure does contain a good distribution of trace elements though, something most NPK chemical fertilizers lack. Remember that manures have a relatively low nutrient content, much of which isn't readily available.

II. COMPOST: How to Make it and Use it

What is Compost?: It's made by letting plant and animal wastes partially decompose in a compost pile or pit. The end product is well on its way to becoming dark, earthy smelling humus, that great soil improver (see p. 4).

What's it Made Out of?: Garden and crop residues like leaves, stalks, grass, weeds; manure is a good additive; table scraps are OK, but meat attracts flies and makes for maggots.

What Goes on in a Compost Pile?

Bacteria and fungi break down the residues into compost by feeding on it. They use carbon for energy and nitrogen for protein and also need air. They produce a lot of heat in the process; a properly made pile will reach 158°F in a couple days and then gradually drop. The pile shrinks to about half its size during composting, since the microbes "burn" up a lot of the carbon.

The Secrets of Rapid Composting

Most compost piles take 2-6 months to break down; that's because it's damn hard to meet all conditions for rapid composting:

1. Finely Chopped Material: This gives much more surface area for the microbes to work on; you need a shredder to do a good enough job for rapid composting (14-17 days); ideal size is less than 1½".

2. Aeration: The microbes thrive on air, so the more often you turn the pile, the quicker the process: turning a large pile with any type of frequency (1-2 times a week is ideal) is a lot of work.

3. Enough Moisture: The pile should contain about 50% water; if it's too dry or too wet, the microbes don't thrive. It needs to be remoistened periodically. It should feel wet but not soggy.

4. Enough Insulation to Hold in Heat: Do this by using a bin (wood, cement, etc.) or hole or make the pile large enough so it's self-insulating (about 4-6 ft. high X 6 ft. wide X 6 ft. long).

5. The Right CARBON:NITROGEN ratio: The microbes need carbon for energy and N for protein. Strawy or tough residues (stalks or tall old grass) usually have too much carbon compared to nitrogen, which makes it difficult for the microbes to break it down (not enough protein available). Sawdust has the same problem. Young grass clippings or other immature green vegetation is the opposite - it's got more N than needed, so the microbes turn the excess into ammonia gas which can be lost.

The ideal carbon-nitrogen ratio is around 30:1 to 35:1. The trick is to blend in strawy materials (too wide a C:N ratio) with less coarse ones (too lean a C:N ratio) for a more balanced mix. Here's the C:N ratio of some common materials:

Sawdust (fresh) 500:1	Fresh manure 15:1 to 20:1
Sawdust (rotted) 210:1	Strawy manure 50:1 or more
Straw 50:1 to 130:1	Young grass clippings 12:1
Sugarcane trash 50:1	Leaves 40:1 to 80:1

Some Other Composting Guidelines

1. How about adding lime?: Some people insist that lime or wood ashes are needed to keep acidity down; not so, though you might want to add a bit when using an especially acid material like oak leaves (about a pint or so per sq. yard on each layer).

2. What about adding soil?: Most methods include adding an inch thick layer of soil every so often while building the pile; it's supposed to supply needed microbes, but studies show that they're already there in sufficient numbers right on the very organic stuff you're adding. Soil may help absorb any released ammonia though. Some recommend scratching up the ground under the pile-to-be to promote soil contact with the pile bottom.

3. Are Chemical Fertilizers Needed?: Some N fertilizer may be needed if you can't get enough organic material with a narrow C:N ratio; a couple pounds per layer will do; you can use an NPK fertilizer for a general nutrient beef-up.

4. What about those compost "activators" you see advertised?: Studies have shown they're unnecessary.

HOW TO MAKE COMPOST

There are countless methods, ranging from using ventilated garbage bags or homemade rotating barrel composters to using piles or pits. The speed of composting depends how close you come to meeting all the requirements on p.62. It'll take from 2 weeks to 6 months. You can use it long before it becomes completely crumbly.

The Pile Method

There are numerous variations, but here's an old standby:

1. Start with a 12" thick layer of organic material; chop it up if possible.

2. Throw on a 2" layer of manure if available and then a 1" layer of soil.

3. Repeat steps 1 & 2 til the pile is 4-6 ft. high.

4. Be sure to moisten each layer (fresh green material will have enough moisture already. Don't allow heavy rains to leach out the pile; keep it covered with plastic or slope the sides to shed water.

5. The more often you turn it, the quicker it'll compost; 1-2 times a week is ideal but 1-2 times a month will help. You may have to remoisten the pile periodically.

The Pit Method

This helps hold in heat. Dig 2 adjacent pits (dimensions unimportant) and fill one as per the pile method. Cover the top with earth or plastic. To turn the compost, just transfer it from one pit to the other; if you don't turn it at least once a week, oxygen is likely to run short.

What if it Doesn't Heat Up?

Check back to the 5 composting essentials on p.62. Most likely it's lacking N or has too much or too little water. Compost made by the pit method needs frequent turning for aeration.

HOW TO USE COMPOST

What's its Nutrient Value?

That depends a lot on what it's made from and how much (if any) chemical fertilizer you added. Like manure, it's definitely a low-analysis nutrient source, especially since much of the N and P aren't immediately usable. It also contains micronutrients, but manure is probably a better source. Common N-P-K ranges for composts are like so: (wet weight basis)

N: 0.75%-1.5%

P_2O_5: 0.25%-0.5%

K_2O: 0.5%-1.0%

Look at compost primarily as a soil improver (like manure) with the added side benefit of some fertilizer value.

Applying Compost

Unlike manure, you don't have to worry about N losses from leaving it on top of the soil; it can be used as a mulch, but to have effect as an immediate soil improver, it should be thoroughly worked into the topsoil.

How Much?: Large amounts are needed to be effective, say around 10-15 tons/acre (0.5-0.75 lbs./sq. foot or 2.5-3.5 kgs./sq. meter). Don't go over about a pound per sq. foot.[1] An eyeball application would be a ¼-½" thick layer over the soil surface. Use the strip or slot method when scarce, confining it to the crop row or hill. A gallon of fresh compost weighs about 5 lbs. (about 3 lbs. when dry).

*1. Per application; there's no harm using higher rates, but you're better off using moderate amounts to allow a likely limited supply to cover more area.

III. OTHER SOURCES OF ORGANIC FERTILIZERS AND SOIL IMPROVERS

You'll find other organic fertilizers and soil improvers in your area. Some soil improvers like rice hulls, sawdust, and cottonseed hulls have little or no fertilizer value, while some of the more concentrated organic fertilizers like blood meal and cottonseed meal aren't usually applied at high enough rates to improve soil physical condition (they're valued as animal feeds and are likely to be expensive).

Here's the N-P-K content of some common sources of organic matter: (these are averages; actual values vary widely)

	N	P_2O_5	K_2O
Bat Guano	10%	4%	2%
Blood Meal	12	2	1
Bone Meal, steamed	2	15-20	0
Coffee Grounds	2	0.3	0.3
Cottonseed Meal	6	3	1
Feathers	15	0	0
Fish Meal	10	4	0
Hair	12-16	0	0
Peat Moss	1	0	0
Seaweed	0.3	1.3	2.3
Wood ash	0	trace	2-10%

The "High Analysis" Organic Fertilizers

Bat guano, blood meal, bone meal, cottonseed meal, fish meal, etc. are fairly high analysis and are used at much lower rates than compost, manure, and other weaker sources of nutrients. Rates of 2-5 lbs. per 100 sq. ft. (10-25 kgs./100 sq. mts.) are commonly recommended. Bone meal is a very slowly available form of P, and most agronomists don't recommend it. Blood, cottonseed, and fish meals are especially good natural sources of micronutrients.

Other Organic Fertilizers and Soil Improvers

Cottonseed Hulls: A by-product of making cottonseed meal. They have little fertilizer value but are good for loosening soil.

Peat Moss: Likely to be unavailable or expensive in your area. It has no fertilizer value but is a great soil conditioner with a high water holding capacity; it's a common ingredient of most potting soil mixes in the States. Most peat is on the acid side, especially Sphagnum (pH 3.5) so lime must be added (see p.35). Sphagnum has a natural ingredient which inhibits damping-off disease of young seedlings.

Rice Hulls: No fertilizer but a great soil conditioner and mulch material (makes a great "grow through" mulch; see p. 35.

Rotted Coconut Husks: See p. 35.

Sawdust: Very low in N and P but a great source of organic matter for soil conditioning and mulching. CAUTION: Sawdust and other low N additives like rice hulls can cause a temporary tie-up of N unless fertilizer N is added; use about 1 lb. of 16-20-0 per 8 gals. of sawdust (it'll help make up for the low P content too). Or mix 4 parts sawdust with one part chicken manure.

Seaweed: A great mulching material and soil improver; fair nutrient value. Apply at rates up to 125 lbs./100 sq. ft.

Sea Cucumbers: The PATS ag trade school on Ponape (Eastern Carolines) uses them as an effective fertilizer on vegies. They let them ferment in a drum for a couple weeks and then apply in a 50-50 mix with water as a [illegible]-dressing.

IV. GREEN MANURE CROPS

Crops like clover, cowpeas, soybeans, oats, and even weeds can be plowed under in the green, immature stage to increase soil organic matter. If the green manure crop is a legume, considerable nitrogen may be added.*1

Despite these advantages, it's unlikely that green manuring will be feasible for your farmers:

1. Most farmers won't want to take their land out of production to grow the green manure crop.
2. In drier areas, a green manure crop can seriously deplete soil moisture needed for the succeeding cash crop.
3. The increase in soil humus can be very short-lived; due to their narrow C:N ratios and tropical temperatures, the green manure's organic matter breaks down quickly.
4. The amount of N added by a legume green manure crop varies a lot and can often be more economically supplied by chemical fertilizer.

*1. Early flowering stage is the best time to plow under most green manure crops.

VI. MULCHING: It Could be Your Soil's Best Friend

Mulching consists of covering the soil surface with a layer of organic matter (or plastic) and is an especially beneficial practice for vegies. The big advantages of mulching are:

1. It cuts down soil water loss by evaporation and is ideal for sandy soils or raised beds which dry out quickly.
2. It suppresses weeds.
3. It insulates the soil from temperature extremes; organic mulches like sawdust and straw help keep soil cool in hot weather (helpful to "cool season" crops like lettuce, broccoli, cabbage, etc.).
4. It keeps vegetable fruits like cucumbers and tomatoes off the ground to reduce rotting.
5. It adds organic matter.
6. It protects soil from erosion losses.
7. It encourages earthworms.

Common Mulching Materials: Rice hulls, sawdust, chopped corn cobs, manure, rice straw, grass, leaves, newspaper, salt marsh hay, compost. Plastic sheeting is a common mulching material in the States; black plastic suppresses weeds.

When and How to Mulch

Mulch can be applied shortly after the crop comes up, but avoid getting it too near the young plants at first. Fine materials like sawdust and rice hulls can be put on about 1-2" thick, while a 2-4" layer is better for fluffy stuff like straw. A newspaper mulch should be about 4-6 pages thick.

Plastic Mulch: Both clear and black plastic can be used; clear plastic may warm up the soil too much in hot weather and also won't control weeds.

Using Mulches to Prevent Seed "Washout": See p.35.

Problems with Mulches

Snails and slugs are more common with mulches; baiting may be necessary (moisten bait with stale beer; it's twice as effective). Keeping the mulch 3-4" from the plants helps.

Mulching is recommended even for very rainy climates (i.e. on raised beds); the PATS ag trade school on Ponape island uses mulch successfully on raised vegie beds (clay soil) under 190" annual rainfall; even very wet climates can have yield stunting dry spells, and mulch is good protection. Coconut yields on Pacific atolls have been increased 100-200% by using cut undergrowth as mulch instead of burning it.

V. EARTHWORMS

How They Benefit the Soil

1. They eat soil in order to burrow and to feed on its organic matter; this speeds up the conversion of organic forms of nutrients into usable mineral forms. Earthworms don't manufacture any nutrients themselves, but the excreted "castings" have excellent fertilizer and soil conditioning value.

2. They help mix and redistribute organic matter; under favorable conditions, they'll transport 20 tons of soil to the surface per acre yearly.

3. Earthworm channels improve soil aeration and drainage.

Can Earthworms Turn a Sick Soil into a Healthy One?

A soil with lots of earthworms is sure to be a super healthy one, but it's no simple matter of cause and effect. Adding the little wrigglers to a lousy soil will get you nowhere; they won't survive, let alone multiply, unless the soil is reasonably healthy to begin with! It's a Catch-22. The best approach is to promote their natural presence by shaping up the soil; here are some guidelines:

1. Earthworms don't like very acid soils (below pH 5.5).

2. They like lots of organic matter.

3. Mulching really helps by keeping the soil moist and providing feed.

4. Good drainage is important.

5. Insecticides (especially those applied to the soil) and some herbicides are toxic to them.

6. Very high rates of chemical fertilizers (mainly N and K) will discourage them, though there's little evidence that moderate rates are harmful.

Earthworms for Composting and for Feed

Earthworm Compost: You can raise earthworms in wooden-sided beds about 12" deep or in shallow pits (gravel in the bottom for drainage) filled with a high organic matter mixture. Most fresh manures should be allowed to partly decompose to prevent excessive heat; leaves, crop residues, and shredded cardboard are also good worm food. It'll take a month or two for the worms to work over the material and make a valuable compost-like product. It's important to keep the beds moist.

Worm compost can be made out of 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 and running; a couple inches of limestone is place at the bottom to counteract the manure's natural acidity. Keep the pits moist and turn the mixture every 2-3 weeks so it doesn't get packed. It's best to use a commercial breed of worms (red variety) that is faster breeding than the usual soil types.

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

Where to Get More Info on Worms

Write to ICE (Information Collection & Exchange), ACTION/ PEACE CORPS, Washington, D.C. 20525 for specific info on earthworms. PC/W has also shipped worms overseas. One recommended guide is Raising Earthworms for Profit, Earl B. Shields, Box 472, Elgin, IL 60120 (cost is $2.00 U.S.).

PART VII

CHEMICAL FERTILIZERS

I. SOME IMPORTANT ODDS & ENDS

Chemical fertilizers (also called "commercial", "inorganic", or "mineral" fertilizers) are much higher strength than compost or manure but lack their soil improving qualities. As we've seen though, most of your farmers won't have enough organic materials to cover more than a part of their land. Chemical fertilizers are usually a necessary ingredient for producing profitable crop yields on a commercial scale. Despite their ever-increasing cost, they can still easily return $3-$5 for every $1 spent, especially when combined with other complementary practices like improved seeds and pest control. Remember that chemical fertilizers and organic materials tend to give the best results when applied together rather than alone.

Types of Chemical Fertilizers

Granules, Powders, Liquids: For soil application, granules are the most common, though full-strength liquid ones are available too. There are also foliar types (for spraying on the leaves) that come as low-strength liquids or soluble powders (see p. 85).

Nutrient Content: Most granular fertilizers contain one or more of the "Big 3" (N, P, K), varying amounts of sulfur and calcium (as carriers), and very low or nil amounts of micronutrients. Some like ammonium sulfate or superphosphate have only one of the "Big 3", while others like 16-20-0 and 14-14-14 contain two or all 3. An NPK fertilizer like 12-24-12 is often called a "complete" fertilizer, but that's a misnomer. Anyway, these NP or NPK fertilizers can be either mechanical or chemical mixtures.

HOW TO READ A FERTILIZER LABEL

All reputable commercial fertilizers carry a tag or label that gives their nutrient content, not only of NPK but also any significant amounts of sulfur, magnesium, and micronutrients.

The 3-Number System: It gives the NPK content in that order, usually in terms of N, P_2O_5, and K_2O. The numbers always refer to percent. A 12-24-12 fertilizer contains 12% N, 24% P_2O_5, and 12% K_2O; that's the same as 12 lbs. N, 24 lbs. P_2O_5, and 12 lbs. K_2O per 100 lb. sack. A 0-21-0 fertilizer contains no nitrogen or potassium but has 21% P_2O_5.

The Fertilizer Ratio: It's the ratio of NPK that the fertilizer has. A 12-24-12 fertilizer has a 1:2:1 ratio and so does a 6-12-6; 15-15-15 and 10-10-10 both have 1:1:1 ratios.

Reading the Label: A typical one might look like this (I'm including English and Spanish in this one, but most are in just one language):

NET WEIGHT 100 lbs.

(Peso Neto: 100 lbs.)

10 - 20 - 10

Total Nitrogen Nitrógeno Total	(N)	10%
Available Phosphoric Acid Acido Fosfórico Asimilable	(P_2O_5)	20%
Water Soluble Potash Potasa soluble in agua	(K_2O)	10%

N, P_2O_5, K_2O vs. N, P, K: What Gives?

Note that the N content is expressed in terms of N but that the P and K content is listed in terms of P_2O_5 and K_2O (called phosphoric acid and potash). Most countries use this N-P_2O_5-K_2O system, though a few are switching to a straight N-P-K basis. Either way, a fertilizer's nutrient content is the same in terms of strength (i.e. a given dis-

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Note that the N content is expressed in terms of N but that the P and K content is listed in terms of P_2O_5 and K_2O (called phosphoric acid and potash). Most countries use this N-P_2O_5-K_2O system, though a few are switching to a straight N-P-K basis. Either way, a fertilizer's nutrient content is the same in terms of strength (i.e. a given distance is the same, whether it's in miles or kilometers). Just in case your country uses a straight NPK system for fertilizer labels and recommendations, here's how to convert between the two systems:

$P \times 2.3 = P_2O_5$ $\quad P_2O_5 \times 0.44 = P$

$K \times 1.2 = K_2O$ $\quad K_2O \times 0.83 = K$

Here's 2 sample problems to clear up any confusion:

PROBLEM #1: Suppose your country uses the straight N-P-K system and you see a fertilizer labelled 16-10.5-6.5. What would its formula be on an N-P_2O_5-K_2O basis?

SOLUTION: Since $P_2O_5 = P \times 2.3$, multiply the fertilizer's P content by 2.3; convert K to K_2O by multiplying the fertilizer's K content by 1.2. You should end up with a 16-24-8 formula on an N-P_2O_5-K_2O basis.

PROBLEM #2: Suppose you receive back soil test results that recommend applying 30 lbs. actual P per acre, but the phosphorus content of your fertilizer is expressed in terms of P_2O_5. How much P_2O_5 would be needed to supply 30 lbs. of actual P?

SOLUTION: Since $P_2O_5 = P \times 2.3$, you'd multiply the 30 lbs. actual P by 2.3 and find out that about 69 lbs. P_2O_5 will supply 35 lbs. of actual phosphorus.

DON'T worry a lot about this, because you're unlikely to run into it. Again, the N-P_2O_5-K_2O system is by far the most common, and it's the one this manual uses.

WHAT'S CHEMICAL FERTILIZER MADE OUT OF?

Most of the N comes from combining ammonia gas with carbon dioxide or nitric acid; phosphorus fertilizers are made by adding sulfuric or phosphoric acid to phosphate rock; potassium comes from mining potassium chloride or sulfate.

Why don't the 3 numbers in a fertilizer formula add up to 100?: Ammonium nitrate (33-0-0) contains 33% N, but what about the other 67%? Its formula is NH_4NO_3 which shows that the rest of the weight is made up of hydrogen (H) and oxygen (O); there's no way to find a sack containing 100% N, since pure N is a gas (and plants can't use it anyway).

Let's take another example. Single superphosphate contains about 20% phosphorus on a P_2O_5 basis (0-20-0); its chemical formula is $Ca(H_2PO_4)_2 \cdot CaSO4$, so you can see that the rest of the weight is made up of calcium (Ca), hydrogen, oxygen, and sulfur (S).

A RUNDOWN ON COMMON CHEMICAL FERTILIZERS

I. NITROGEN FERTILIZERS

Nearly all N fertilizers contain either ammonium (NH_4^+) or nitrate (NO_3^-) nitrogen. Nitrate N is quicker acting and more mobile and easily leached, but don't forget that ammonium N is pretty quickly converted to nitrate N in warm soils (all of it within 7-10 days).

Ammonium Nitrate (33-34% N): A 50-50 mix of ammonium and nitrate N; quick acting but quickly becomes slushy in high humidity (keep the sacks sealed). If left on the soil surface at pH's above 7.0, some will be lost as ammonia gas. Can be explosive if mixed with oil or exposed to fire. It has an acid effect on the soil (see p. 76).

Ammonium Nitrate with Lime (20-21%N): Same as above but it's coated with dolomitic limestone to neutralize acidity and reduce absorption of humidity.

Ammonium Sulfate (20-21% N): Also contains sulfur (about 23% S or 69% SO_4); good handling and storage properties; has an acid effect on the soil; some N may be lost as ammonia gas if applied to the soil surface above pH 7.0 w/o covering.

Urea (45-46%N): Has the chemical formula $CO(NH_2)_2$, and it's N is in the amide form but is quickly converted to ammonium and then to nitrate by soil microbes. Regardless of soil pH, some N will be lost if it's left on the soil surface, especially when applied to pastures (up to 35% loss). It's the most high-strength source of N available in solid form. Can cause "burning" if placed to near seeds or seedlings. May sometimes contain excessive amounts of biuret which is very toxic to plants, but this is rare and due to faulty manufacture. Has an acid effect on the soil. Can be fed as a protein source to ruminant animals (cattle, sheep, goats); the rumen bacteria convert it to protein BUT it can be very toxic at anything but low levels (vinegar is the antidote) and must be fed in combination with certain other feeds. Tends to absorb moisture.

Sodium Nitrate (16-0-0): Also called Chilean nitrate; tends to be high cost per lb. of N due to its low strength. Can easily "burn" seeds or seedlings because of its high "salt" content (see p. 86). Has a basic effect on soils. Absorbs humidity.

Potassium Nitrate (13-0-44): See under K fertilizers.

Ammonium Phosphate Fertilizers: See under P fertilizers.

Mixed Fertilizers: Lots of mixed fertilizers like 10-20-10, 14-14-14, 20-20-0, etc. contain N.

Anhydrous Ammonia (82% N): The highest strength N fertilizer available; it's stored under pressure as a liquid but reverts to gas upon exposure to air; it's applied with a special applicator under strict safety precautions (it can cause blindness and fatal lung damage); has an acid effect on the soil.

What about "Time Release" or "Slow Release" N Fertilizers?

They're coated or mixed with substances that slow down their solubility and the speed of microbial conversion to leachable nitrate. Trouble is, they're usually too expensive to be used on a commercial scale.

II. PHOSPHORUS FERTILIZERS

Single Superphosphate (16-22% P_2O_5, 8-12% S): A common P fertilizer and also a good sulfur source. Nearly all the P is "water soluble" but that doesn't keep it from being tied up in the soil. Has no effect on soil pH.

Triple or Concentrated Superphosphate (42-48% P_2O_5): A higher strength source of P but low in sulfur (1-3%). Its P is nearly all water soluble but still subject to soil tie-up.

Ammonium Phosphate Fertilizers

1. Mono-ammonium Phosphate (11-48-0, 12-61-0): Tends to give better results than di-ammonium phosphate on alkaline (basic) soils. Low in sulfur.
2. Di-ammonium Phosphate (16-48-0, 18-46-0, 21-53-0): Good P source but may injure the seed be ammonia release if placed too close, esp. on basic soils. MAP is less likely to burn, but DAP is safe if applied correctly (see p. 86).
3. Ammonium Phosphate Sulfate (16-20-0, 13-39-0): Both are also good sources of sulfur (9-15% S in 16-20-0, 7% S in 13-39-0).

All the ammonium phosphate fertilizers have an acid effect on the soil.

Mixed Fertilizers: Numerous kinds have P (20-20-0, 15-15-15, etc.).

Heat Treated Rock Phosphates: These vary in P content; made by heat treating natural phosphate rock to increase its P availability (very low); none of its P is water soluble, although most will become slowly available under acid conditions; may be a cheap P source in countries with phosphate deposits but is only recommended for acid soils and should be finely ground; don't use it as the sole source of P for short-term annual crops (corn, etc.) - it won't become available fast enough.*1

Basic Slag (15-25% P_2O_5): A by-product of steel making; a readily available source of P best used in acid soils; has a basic effect on soils.

Bone Meal: See under Organic Fertilizers.

What's the Difference between Water Soluble Phosphorus and Water Insoluble Phosphorus?

Don't be confused by the term "water soluble" phosphorus. It just means that the P is readily soluble in water and will move out of the granules into the soil quickly; it doesn't mean that it'll be 100% available to plants - that depends on the soil's ability to tie up P. For annual crops, at least 50% of the fertilizer's P should be water soluble (it'll say on the label). Heattreated rock phosphate contains only citrate soluble P - that's why it's only recommended for acid soils where it can be dissolved. Raw phosphate rock and bone meal are worse off, containing only insoluble P which has very low availability.

III. POTASSIUM FERTILIZERS

Potassium chloride (muriate of potash, 0-0-60), potassium sulfate (0-0-50), and potassium nitrate (13-0-44) are common K sources as well as mixed fertilizers like 14-14-14. Tobacco, potatoes, and sweetpotatoes are sensitive to high amounts of chlorides.

IV. SECONDARY NUTRIENT SOURCES (Calcium, Magnesium, Sulfur)

Calcium & Magnesium

They're most commonly supplied as limestone (only Ca) and dolomitic limestone (Ca and Mg) when raising soil pH. Gypsum (calcium sulfate) has no effect on pH and is used to supply plants with a high Ca requirement that prefer an acid soil (like peanuts).

Magnesium sulfate (Epsom salts, 9-11%Mg) and potassium magnesium sulfate (11% Mg) are other sources of Mg and have no effect on soil pH. The Mg content of fertilizers is often expressed in terms of MgO (magnesium oxide); the conversion is Mg X 1.66 = MgO, MgO x 0.6 = Mg.

*1. Heat treated rock phosphates work well in high organic matter soils.

Supplying Sulfur

Some common fertilizers are good S sources like single super (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 a fertilizer, the lower its S content (i.e. triple super has 1-3% S). Sulfur deficiencies are on the increase in non-industrial areas, due to the growing use of high analysis fertilizers. It's a good idea to include a sulfur bearing fertilizer in your program, especially on acid, sandy soils. Organic matter is a good source of S.

The S content of fertilizers is often expressed in terms of SO_4 (sulfate); 3 lbs. SO_4 = 1 lb. actual S.

V. MICRONUTRIENT FERTILIZERS

Some mixed fertilizers may contain varying amounts of micronutrients (check the label) but usually too little to correct deficiencies; if a meaningful amount is present, it may appear as a 4th number in the fertilizer formula, referring to the particular micronutrient.

Separate micronutrient fertilizers like copper sulfate, iron sulfate, zinc sulfate, manganese sulfate, and borax are available for soil or foliar applications; remember that soil tie up of added Mn or Fe is often a problem on deficient soils (see p.41). Chelated forms that greatly cut soil tie up are available too. Some fungicides like Maneb (contains Mn) and Zineb (contains Zn) can supply micronutrients in conjunction with disease control.

What about Foliar Fertilizers, Anyway?: See p.85 .

HOW SOME FERTILIZERS AFFECT SOIL pH AND WHAT TO DO ABOUT IT

Fertilizers can be acid, basic, or neutral in their effect on soil pH:

1. All ammonium N fertilizers (except ammonium nitrate with lime) are acid forming; that's because the conversion of ammonium (NH_4) to nitrate (NO_3) releases acid forming hydrogen ions. The same goes for Urea and most mixed fertilizers (15-15-15, 20-20-0, etc.).
2. Nitrate N fertilizers that have the nitrate combined with a strong base have a slightly basic effect (calcium nitrate, potassium nitrate, sodium nitrate).
3. The straight P or K fertilizers have no effect on soil pH: potassium chloride, potassium sulfate, superphosphates.
4. Large applications of manure and composts have an acid effect.

So What's this Mean?

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 of pH drop depends on the kind and amount of fertilizer applied and the buffering capacity (exchange capacity; see p. 38) of the soil. Since clayey soils tend to (but not always) have a higher buffering capacity, they're usually more resistant to pH change than coarser soils.

So why use acid forming fertilizers?: they're usually the most available and econonomical and are actually beneficial on alkaline soils.

Why not Add Lime to an Acid Fertilizer?: DON'T! You'll lose a lot of N as ammonia gas. Many fertilizer labels state the amount of lime needed to neutralize the acidity per 100 lbs. of the fertilizer, but that's just a legal requirement. Don't add lime to the soil each time either; it's unnecessary and time consuming; most of your farmers can't afford high enough fertilizer rates to markedly change pH in a year or two anyway.

The table below compares the relative acidity of acid forming fertilizers; you'll see there's quite a difference among them:

Relative Acidity of Acid Forming Fertilizers

FERTILIZER	% Nitrogen	Lbs. of pure limestone needed to counteract the acidity pro-produced per: 100 lbs. fertilizer	per lb. of N
Ammonium nitrate	33-34%	60 lbs.	1.8 lbs.
Ammonium sulfate	20-21%	110 lbs.	5.3 lbs.
Ammonium phosphate sulfate	16%	88 lbs.	5.3 lbs.
Urea	45-46%	84 lbs.	1.8 lbs.
Mono-ammonium phosphate (11-48-0)	11%	58 lbs.	5.3 lbs.
Di-ammonium phosphate	21%	74 lbs.	3.5 lbs.

The far right column is the most relevant when comparing the fertilizers, and you can see that ammonium sulfate, ammonium phosphate sulfate, and mono-ammonium phosphate are nearly 3 times as acid forming as urea and ammonium nitrate. Many experts feel that these figures are too conservative and that the figures for urea and ammonium nitrate might well be doubled and the others raised by 30%. Read over the chapter on liming.

II. HOW TO APPLY CHEMICAL FERTILIZERS

You can't expect good results from fertilizers if you don't know HOW and WHEN to apply them and HOW MUCH to use. It's a common weak point among PCV's, farmers, and a surprising number of extension agents and pamphlets. Yet the basic guidelines are pretty straight forward. Read over the next few pages, and you'll go a long way toward helping your farmers maximize their return on fertilizer use.

Let's start off with some important How and When application guidelines for the nutrients:

NITROGEN

Even though ammonium N is fairly resistant to leaching, it's converted to leachable nitrate within a week or so under warm, moist soil conditions. The coarser the soil texture and the higher the rainfall, the greater the leaching losses.

How to Combat Leaching of N: As a general rule for annual crops (corn, sorghum, tomatoes, etc.), apply 1/3 - 1/2 of the total N at (or near) planting (or transplanting) time, usually as part of an NP or NPK fertilizer. Apply the remaining N as one or more sidedressings* later on in the growing season when the plant's demand for N picks up; use a straight N fertilizer like urea, ammonium sulfate, or ammonium nitrate.

How Many Sidedressings?: For crops like corn, sorghum, and dryland rice, one sidedressing is usually OK except on sandier soils under high rainfall (use two). The single sidedressing

* applications of fertilizer along the crop row of growing plants

is made 30-40 days after planting (corn is about knee high). The longer season crops like tomato and eggplant normally get 2-4 N sidedressings at 3-4 week intervals. Grass pastures are commonly topdressed with N 3-6 times during the wet season, following a once a year NP or NPK application.

Where to Place Fertilizer N

As an NP or NPK Fertilizer: When applying N at planting or transplant time as part of an NP or NPK fertilizer, be sure to place it 3-6" (7.5-15 cms.) deep; reason is that P and usually K move very little in the soil and need to be placed in the root zone at the start; not many roots grow in the top inch or two of soil - it's not continually moist enough (unless mulched) for roots to prosper (pastures can absorb surface applied P and K though). Here's 3 effective methods of applying an NP or NPK fertilizer:

1. In a continuous band that runs 2-3" out from the seed row and 2-3" below seed depth.
2. In a half-circle 3-6" deep and 4-6" out from the transplant.
3. In a hole 4-6" deep and 4-6" away from the seed hole or transplant. Not as effective as #1 and #2.

As an N sidedressing: There's no need to place a straight N fertilizer deep since rainfall will move it down into the root zone. Work it in a bit (like ½-1") to keep it from being carried away by surface water flow; urea should always be worked in to avoid ammonia gas loss. Ideal time to sidedress is right before a weed cultivation - the cultivator or hoe can work it into the soil. Here's 2 effective sidedressing methods:

1. In a continuous band [*1] along the row about 4" or more out; crops with spreading root systems like corn and sorghum can be sidedressed midway between the rows with no loss of effect.
2. Crops with wide in-the-row spacings like tomatoes, eggplant, and pepper are commonly sidedressed in a half-circle about 6" or so out from the plant. Or use a continuous band.

PHOSPHORUS APPLICATION GUIDELINES

Remember these 4 vital facts on P:

1. It's virtually immobile in the soil, so deep placement (3-6") is essential (pastures are the exception).

*1. No need to make a wide band; the N will spread out as it moves downward through the soil.

2. It's easily tied up by the soil; only about 5-20% of the fertilizer P you apply will actually be available to the crop. Application method has a big influence on tie-up (see below).

3. Young plants need a high concentration of P in their tissues for good root growth; this means that P should be applied at or near planting or transplant time.

4. There's no value in making additional P applications after the initial ones, yet lots of farmers waste money by sidressing with 12-24-12, 16-20-0, etc. Besides, you'd damage the roots trying to get P down 3-6" on a growing crop. Splitting P applications won't cut down on soil tie-up either.

How to Minimize P Tie-up

1. Use localized placement (band, half-circle, hole): The low to medium rates (20-60 lbs. P_2O_5/acre or 25-65 kgs./hectare) most of your farmers will be using are much better utilized if locally placed instead of broadcast (p.83). This applies to P, NP, and NPK fertilizers. Pastures are an exception.

2. Compost and manure help decrease soil P tie-up.

3. Maintain soil pH within the 5.?-7.0 range if possible.

4. When applied along with P, N helps increase P availability and uptake.

Should P Ever be Broadcast?

Broadcasting maximizes P tie-up by spreading the fertilizer too thin and exposing each granule to full soil contact. To overcome the increased tie-up, broadcast rates may need to be 2-10 times or more higher than with localized placement. Broadcasting is a good way to build up the soil's general P content, but few farmers can afford the huge amount needed. Here are 2 exceptions:

1. Broadcasting can be used on very small plots and is the best method for seedboxes; shoot for rates of at least 200 lbs. P_2O_5/acre (220 kgs./hectare).

2. Broadcasting works fine on pastures, even at low to medium rates.

Except on pastures, broadcast P must be worked into the soil at least 3-4" deep (preferably into the whole topsoil).

POTASSIUM GUIDELINES

K ranks between N and P in mobility, so leaching losses aren't usually important except on coarser soils or under very heavy rainfall. K should be applied at or near planting or transplant time as part of an NPK fertilizer and should be placed 3-6" deep (7.5-15 cms.). Where leaching losses are likely to be high, K can be applied in 2-3 applications; this is also recommended for pastures to help reduce "luxury consumption" of K (see p.46). K tie-up is a problem on some soils but nowhere near that of P tie-up.

Broadcast applications of K: Farmers in the States and Europe commonly make periodic heavy broadcast applications of K to help build up soil levels; they can be very effective and may last for several years but aren't recommended where there's high leaching losses or where K tie-up is a problem (see p. 46). Such heavy K applications may induce magnesium deficiencies in some crops on soils with borderline Mg levels.

Save those Crop Residues!: About 2/3 of a plant's K is found in the leaves and stems vs. about 1/3 in the ear, pod, or fruit; however, about 1/2-2/3 of the K in root crops is found in the harvested root itself. Burning residues does not destroy K but only N, sulfur, and organic matter.

SULFUR

Sulfur is usually applied as a sulfur bearing fertilizer like single super, ammonium sulfate, etc. so the application method is dictated by the principal nutrients in the fertilizer. Sulfur is mobile and readily leached.

CALCIUM & MAGNESIUM

1. Ca is more often applied as a liming material to lessen acidity than as a nutrient; even very acid soils usually have enough Ca for plant needs. Some crops like peanuts and tomatoes have extra high Ca needs, and deficiencies can be cured by liming (if the pH is too low) or by applying gypsum (no effect in pH) in a band near the row (it's mobile) or sprinkled over the peanut plants.
2. A liming material like limestone or burned lime must be evenly broadcast and then worked into the topsoil. Dolomitic limestone will cure an Mg deficiency while lessening acidity.
3. Epsom salts (magnesium sulfate) or potassium magnesium sulfate have no effect on pH and can be applied using the same methods as for NP or NPK fertilizers. 20-25 lbs. actual Mg/acre (200-250 lbs. epsom salts) will do it.*1

MICRONUTRIENTS

Soil applications of iron and manganese are often ineffective due to soil tie-up, especially at pH's above 6.8. Using chelated forms will avoid this or you can make foliar appli-

*1. Or spray plants using 15-20 lbs. epsom salts/100 gals. water cations. All the micronutrients can be applied as foliar sprays which is often more convenient, but high applications will burn leaves. Zinc can be mixed with fertilizer and banded or broadcast. Boron may be broadcast or mixed with other fertilizers and banded near the seed (rates of more than 1 lb. actual B per acre may injure germinating seeds of some crops).

GENERAL MICRONUTRIENT RATES FOR DEFICIENCIES*1

Boron: Household borax at tablespoon (15 c.c.) per 100 sq. feet on sandy soils and up to 3 tbs. on clayey soils. Don't O.D. the soil - it's harmful to plants. Or use 10-25 lbs. borax/acre (11-27 kgs./hectare).

Molybdenum: Use 1/2 teaspoon (2.5 c.c.) of sodium molybdate per 100 sq. ft. (mix with fertilizer); or spray plants with a solution of 1/4-1/2 lb. sodium molybdate per 100 gals. water. Liming the soil (if pH is too low) will often cure a deficiency.

Zinc: 10-40 lbs./acre of zinc sulfate (23% Zn); band low rates or broadcast high ones. You can spray plants with a 1-2% solution of zinc sulfate (1.25-2.5 ounces per gal. of water); use a wetting agent.

Manganese: Spray plants with a 1-2% solution of manganese sulfate (1.25-2.5 oz./gal. of water) plus a wetting agent. Use a special chelate form if applying it to the soil.

Iron: A 1-2% spray of ferrous sulfate (1.25-2.5 oz./gal.) plus a wetting agent but may need repeating every few weeks. Chelated iron should be used for soil application (18-36 lbs./acre).

Copper: Use 1½-2 teaspoons (7.5-10 c.c.) of copper sulfate per 100 sq. ft. of soil. Mix with your regular fertilizer.

If using foliar sprays, they usually require more than one application.

*1. When using foliar sprays a wetting agent ("spreader") is important to assure uniform coverage; if a commercial spreader isn't available, use a mild liquid detergent like "Lux" or "Ivory" at 1-2 teaspoons per gal.

FERTILIZER APPLICATION METHODS COMPARED

Let's check out the effectiveness and suitability of 4 common application methods for your farmers:

1. Broadcasting
2. Localized placement: band, half-circle, hole.
3. Foliar applications
4. Through the irrigation water

I. BROADCASTING

The fertilizer is uniformly spread over the soil and then hoed, disked, or plowed in. P and K should be worked 6-8" into the topsoil. Topdressing refers to surface applications on pastures while they're growing. Except on small plots, seed boxes, or pastures, your farmers are a lot better off using localized placement instead. The cons outweigh the pros:

Pros

1. Gives a better distribution of fertilizer in the root zone compared to localized placement; most high capital Stateside farmers combine broadcasting (for large applications of P and K) with banding a small amount of NPK fertilizer near the seed to get plants off and running.
2. Little danger of fertilizer "burn".
3. Labor needs may be better distributed, since the fertilizer is applied before planting time; broadcast applications of P and K may last several years if high rates are used.

Cons

1. It maximizes soil tie-up of P (K also).
2. Low to medium rates of fertilizer (esp. P) are spread too thin.
3. Your farmers can't afford the high rates of P and K needed to overcome #1 and #2; 2-10 times as much P and K are needed when broadcast to equal the effect of localized placement.
4. You fertilize the weeds as well as the crop.
5. Farmers may lack equipment for uniform spreading and for working in P ar K deep enough. Plows and hoes work fine, but dis harrows usually don't work it in deep enough.

II. LOCALIZED PLACEMENT (Band, Half-circle, Hole)

Several Ways to Band Fertilizer

The continuous band method is ideal for close spaced crops like carrots, radishes, and beets or for drill seeded (one seed at a time instead of in "hills") corn and sorghum. Here are several ways to do it:

1. Best placement of the band is 2-3" to the side of and 2-3" below the seed row. This lowers the risk of "burn" and also gets the fertilizer down deep and into the path of the roots. Tractor and animal drawn planters with fertilizer band applicators are available; otherwise this method can be pretty tedious on anything but small plots. One band/row is as good as 2.

2. The farmer can make a 4-6" deep furrow with a wooden plow or hoe, apply the fertilizer along the bottom, and then kick in soil to fill the furrow up to planting depth. This gives a band of fertilizer running under the seeds and a little to each side; as long as there's 2-3" between fertilizer and seed, there's little danger of burning, even at healthy rates.*1

3. A less satisfactory method is to make one furrow at planting depth and place both seed and fertilizer in it; it'll work OK with corn and sorghum with little risk of "burn" at low to medium rates (like 175-250 lbs./acre of 16-20-0 or 14-14-14 or up to 100 lbs./acre of 18-46-0, 16-48-0). Make the furrow wide so the fertilizer can be spread out a bit to dilute it.

Placement Under the Seed: One danger of placing an NP or NPK fertilizer directly under the seed or transplant is that the N and K salts may move upward through the soil as it dries and cause injury (P doesn't burn). Straight P fertilizers are safe to use this way but should be separated from the seed by an inch of soil. Placement of P directly under the seed or transplant often gives great results on tap rooted crops like tomatoes, onions, and cotton. Side-band placement of P is better for fibrous rooted crops like corn, sorghum, and small grains.

Half-Circle Method

Very effective on crops spaced too far apart to warrant banding (tomatoes, peppers, hill planted corn, eggplant, etc.). The half-circle should be located about 3-4" out from the seed group or transplant and 4-6" deep (if using an NP or NPK fertilizer).

"Hole" Method

The least effective of the 3 since it concentrates the fertilizer in a pretty small area; still, it's far better

*1. Sandy soils are more prone to fertilizer burn problems.

than no fertilizer at all. Make the hole 4-6" deep and 3" or so away from seed hills or 4-6" away from larger plants.

Using a Liquid "Starter" Solution

Starter solutions help transplants recover from the shock by providing a readily available source of fertilizer (esp. P for root growth). They're made by mixing 2-4 tablespoons of a high P fertilizer like 12-24-12, 10-30-10, or 14-14-14 with a gallon of water and then pouring about a cup into each transplant hole before putting the seedling in. Let the solution disappear into the soil first. See under "Vegetables" for more info.

Pros and Cons of Localized Placement (LP)

The "LP" method is usually the best one for farmers whose capital or management situation limits them to low or medium rates of fertilizer; the pros far outweigh the cons:

Pros

1. Small to medium rates of fertilizer (esp. P) are much more efficiently used than if broadcast. Gives maximum return per dollar spent.
2. It minimizes the tie-up of P (K too).
3. It doesn't feed the weeds as much.
4. Especially good for crops with less extensive root systems like lettuce, cabbage, onions, radish, potatoes, and cotton.

Cons

1. On low fertility soils, it's hard to produce top yields with the "LP" method alone; confining the fertilizer to a small area doesn't stimulate as extensive root development. Most of your farmers won't have the money or the management skills to shoot for top yields anyway.

III. FOLIAR APPLICATIONS

Foliar applications are mainly suited for applying micronutrients since such small amounts are needed; it's a good way to avoid the soil tie-up of manganese and iron (unless chelates are used).

What about Foliar NPK Fertilizers?: Many liquid and soluble powder NPK foliar fertilizers are available; some advertisements claim large yield increases over using soil fertilizers alone. Research has shown that foliar NPK fertilizers can "green up" a crop but that yield increases are unlikely as long as enough soil applied NPK is used. Some of these products contain various micronutrients but in such low concentrations that they're useless for preventing or controlling deficiencies. The NPK foliar products are highly expensive per lb. of nutrient compared to regular fertilizers. Numerous applications would be needed to supply a good amount of N, P, or K without burning.

IV. APPLICATION THROUGH THE IRRIGATION WATER

Urea and ammonium nitrate dissolve readily in water and are often applied by sprinkler irrigation; don't try this using furrow irrigation - it's too wasteful and non-uniform.

SOME SPECIAL ADVICE FOR FURROW IRRIGATED SOILS

When using an "LP" method on furrow irrigated soils, be sure to place the fertilizer below the level that the irrigation water will reach in the furrow; placement below the high water mark enables mobile nutrients like nitrate and sulfate to move sideways and downwards towards the roots; if placed above the water line, the upward capillary rise of water will carry these mobile nutrients to the surface.

HOW TO AVOID FERTILIZER BURN

Fear of fertilizer burn terrorizes many a PCV, but it's easy to avoid. "Burning" is caused by a high concentration of soluble salts around the seed or roots which prevents them from absorbing water or anything else (remember osmosis?). Either the seeds germinate poorly or the leaves start to turn brown, first at the tips, and the plant eventually dies. The N and K fertilizers are the real culprits, since they have a much higher "salt index" than P fertilizers.

First Aid for Fertilizer Burn: If you're lucky enough to be able to irrigate, liberally apply the water to leach away the salts. Otherwise, pray for rain!

How to Avoid "Burn": Separate the seed and the fertilizer by 2-3" when banding and 3-4" from the seed or transplant when using the half-circle or hole method; burning is more likely on sandy soils than clayey soils; soils in arid or semi-arid irrigated areas are likely to have a high salt content to begin with - burning is even more likely here.

Fertilizers Vary in "Burn" Potential: It's the salts associated with N and K that do the burning; P has little burning potential. The table on the next page gives the relative "Salt Index" of common fertilizers per 20 lbs. of plant nutrients (not per lb. of fertilizer).

Relative Burn Potential of Different Fertilizers

Fertilizer	Formula	Salt Index per 20 lbs. of Plant Nutrients	
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 magnesium sulfate	0-0-22	1.97	
Potassium chloride	0-0-60	1.93	
Urea[•1]	45-0-0	1.6	
Di-ammonium phosphate[•1]	18-46-0	1.6	
Potassium sulfate	0-0-54	0.85	
Single superphosphate	0-20-0	0.4	
Triple superphosphate	0-48-0	0.2	
Gypsum		0.25	LEAST

•1. Urea and DAP may cause more injury than ammonium sulfate since they release free ammonia.

III. HOW MUCH TO APPLY?

WHAT'S THE MOST PROFITABLE RATE OF FERTILIZER FOR A SMALL FARMER?

That depends on:

1. His management ability and capital situation; does he have the money, desire, and ability to follow recommended practices in fertilizer use, pest control, use of improved varieties, etc?
2. Limiting factors other than fertility and how well they can be controlled: low pH, shallow soil, poor drainage, weeds, insects, diseases, rainfall & irrigation, suitable crop variety, etc.
3. The fertility level of the soil
4. Type of crop and probable price; perishable vegies usually have a higher profit potential than storable grain crops, but much more risk is involved due to greater price fluctuations and more sophisticated growing techniques.
5. The cost of fertilizer.

Looks like another complex issue, but we can still arrive at some very useful guidelines. Read on.

Small Farmers Should Usually Aim for Maximum Return Per Dollar; that Means Low to Moderate Fertilizer Rates

As shown by the fertilizer trial results below, crop response to fertilizer follows the Law of Diminishing Returns: (N was the only deficient nutrient in this trial)

Lbs. of Nitrogen Added Per Acre	Yield in Bushels Per Acre*1	Yield Increase
0	12	--
40	54	42
80	84	30
120	104	20
160	119	15
200	129	10
240	136	7
280	141	5
320	144	3

*1. 1 Bushel of corn = 56 lbs. (shelled and at 14% moisture)

Since the efficiency of fertilizer response declines as rates go up, a small farmer who's short on capital should apply low to medium rates of fertilizer. He'll end up with a higher return per dollar spent on fertilizer, be able to fertilize more land, and have money left over to invest in other yield improving practices.

As a farmer's capital situation improves, he can afford to become less efficient and aim more towards maximum profit per acre by applying higher rates of fertilizer. That's like the big supermarket that offers lower prices than the Mom & Pop outfits but makes a much higher total profit due to its larger volume.

A capital-short small farmer is usually better off fertilizing a larger area of land at low to medium rates than a small area of land at a high rate. For example, in the fertilizer trial on the previous page, 160 lbs. of N produced 119 bu. of corn when applied to one acre; if the same amount were spread over 4 acres, a total of 216 bu. would be produced (4 x 54).

The amount of fertilizer that will give the best return per dollar spent depends a lot on the crop, soil, climate, etc., but it's usually on the low to medium side. A high value crop like tomatoes often merits a higher rate than a lower value crop like corn, but the risk is higher and the price fluctuation much greater.

Substitution of Fertilizer for Land: Another factor is that fertilizer can substitute for land by allowing the farmer to produce more corn and beans on less land. That cuts costs and permits more diversity of production.

HOW ABOUT SOME GENERAL GUIDELINES FOR LOW, MEDIUM, AND HIGH RATES OF N, P_2O_5, and K_2O?

OK, but bear in mind the many factors that determine fertilizer rates (see top of previous page). The table below gives a very general guide to LOW, MEDIUM, and HIGH rates of the "BIG 3" (N,P,K) under small farmer conditions and using localized placement of P and K (except on pastures):

	LOW*1 (Lbs./acre or Kgs./hectare)	MEDIUM (Lbs./acre or Kgs./hectare)	HIGH (Lbs./acre or Kgs./hectare)
N	35-55	60-95	100+
P_2O_5	25-35	40-60	70+
K_2O	30-40	50-70	80+

Now check out the qualifications on the next page:

*1. Kgs./Ha. and Lbs./acre are virtually the same (within 10%). Lbs./acre x 1.12 = kgs./Ha.

Qualifications to the "Low", "Medium", "High" Table

1. YOU MUST CONSIDER THE FERTILITY LEVEL OF THE SOIL YOU'RE WORKING WITH as well as the type of crop. A soil high in K would need little or no fertilizer K. Most cropped soils tend to be low in N and low to medium in P; K deficiencies are less common. Grasses and cereal crops (corn, rice, etc.) usually show less response to added K than root crops, bananas, sugarcane, and legumes.

2. The N rates are geared to high users like corn, sorghum, rice, pasture grasses, leafy vegies like lettuce, cabbage, mustard; some fruit vegies like tomatoes (apply less N on eggplant, pepper and cucumber), and potatoes.

3. Most other root crops aside from potatoes have lower N needs than those above; this includes carrots, radishes, beets, onions, manioc (cassava, yuca), and taro.

4. Legumes like peanuts, mungo beans (P. aureus), soybeans, cowpeas and tropical pasture legumes are all very efficient N fixers if properly innoculated or grown on a soil with a good natural population of the right strain of Rhizobia; they need little or no fertilizer N, but most extension pamphlets recommend a starter application of 20-30 kgs./Ha. or Lbs./acre of N (along with the usual P and K) to feed the plants til the Rhizobia begin to fix N (takes about 2-3 weeks).

   Ordinary beans, lima beans, and peas aren't as efficient N fixers and can use up to 50-60 kgs. N/ha. or lbs./acre.

5. Don't forget to take the farmer's management ability into account. You're wasting your time encouraging a farmer to use a "High" rate of fertilizer if he's not willing or able to use other complementary yield improving practices; also remember to check out soil limiting factors like drainage, depth, etc.

Specific Crop Recommendations

Pages 108-35 give more detailed fertilizer recommendations and related guidelines for common crops. Whenever possible, get the soil tested by a reliable lab.

IV. FAULTY FERTILIZER PRACTICES

How to Spot Them and Fix Them

Faulty fertilizer practices are all too common among farmers, PCV's, and a surprising number of extension pamphlets. Let's run through some of the more common mistakes:

(NOTE: Since lbs./acre and kgs./hectare are close equivalents, the fertilizer rates below apply to both; i.e. 100 kgs./ha. is pretty close to 100 lbs./acre)

EXAMPLE 1: 125 kgs. (lbs.) of Urea (45-0-0) per hectare (acre) applied when corn is planted, followed by a sidedressing of 200 kgs. (lbs.) 16-20-0 per hectare (acre) at knee-high stage.

WHAT'S WRONG?: It's backwards! The NP or NPK fertilizer should always be applied at or near planting, never as a sidedressing. Besides, only 1/3 - 1/2 of the total N should be put on at planting to minimize leaching losses. What about the total NPK dosage? It works out to about 88 kgs. (lbs.) N, 40 kgs. (lbs.) P_2O_5, and no K_2O per hectare (acre). The N and P rates are in the acceptable range (see table on P. 89), but some K may be needed unless the soil has a medium to high test level.

EXAMPLE 2: 250 kgs./Ha. (lbs./acre) of 14-14-14 broadcast and left on the soil surface a couple days before planting vegies.

WHAT'S WRONG?: What's right? Broadcasting is a lousy way to use a small amount of fertilizer, especially P. To add insult to injury, it's being left on the soil surface; the P and most of the K will never reach the roots. The fertilizer should be banded instead.

EXAMPLE 3: 300 kgs./Ha. (or lbs./acre) of 15-15-15 applied in a band at corn planting time and placed 2" (5 cms.) deep and 6" (15 cms.) from the row, followed by a sidedressing of ammonium sulfate (20-0-0) at 300 kgs./Ha. (lbs./acre) when corn is tasseling.

WHAT'S WRONG?: The NPK fertilizer is being placed too shallow and too far away from the row. It should be at least 3-4" (7.5-10 cms.) deep and no farther away than 2-3" (5-7.5 cms.) from the row. The N sidedressing is being applied about 3-4 weeks too late; corn and sorghum need the N sidedressing about knee high stage. The soil also may not need any K. Rates are OK.

EXAMPLE 4: 150 kgs./Ha. (lbs./acre) of 12-24-12 applied at tomato transplant time in a half circle 10" (25 cms.) away and 2" (5 cms.) deep, followed by a sidedressing of 200 kgs./Ha. (lbs./acre) of 14-14-14 3 weeks later.

WHAT'S WRONG?: Tomatoes are a heavy NPK feeder; 150 kgs./Ha. isn't enough (2 to 5 times as much is needed, unless soil K level is high). The half-circle is too shallow and too far away from the plants; it should be at least 3-4" deep and about 4" or so away. There's no benefit from sidedressing with an NPK fertilizer like 14-14-14; all the P and K should go on at transplant time (sidedressing K only pays on sandy soils or under a lot of rain); only N should usually be sidedressed. I'd aim for a total N application of 100 or more kgs./Ha. (lbs./acre). See p. 123 for suggested NPK rates.

EXAMPLE 5: 200 kgs./Ha. (lbs./acre) of 0-20-0 applied when grain sorghum is planted, followed by 400 kgs./Ha. (lbs./acre) of Urea (45-0-0) as a side-dressing 35 days later.

WHAT'S WRONG?: Some N should always be applied at planting to most crops (except maybe peanuts, soybeans, cowpeas, mung beans, and peanuts and pasture legumes). Otherwise, you're apt to run into an N deficiency well before sidedressing time. Young plants don't need much N, but soil microbes can cause a temporary N tieup while decomposing the previous crop's residues. The Urea sidedressing is being applied at the right time, but it's much too high a rate except for super farmers with super soil and lots of capital. I'd cut it down to a total of 80-100 kgs. (lbs.) of actual N per hectare (acre) (planting plus side-dressing). P rate is in the OK range though K may be needed.

EXAMPLE 6: 250 kgs./Ha. (lbs./acre) of 12-24-12 applied in a band when peanuts are planted, followed by a sidedressing of ammonium sulfate (20-0-0) at 300 kgs./Ha. (lbs./acre).

WHAT'S WRONG?: Peanuts are a very efficient N fixing legume so little, if any, N is needed *if* the proper *Rhizobia* bacteria are present in the soil or *if* the seeds were properly innoculated with the right *Rhizobia* culture. However, a starter amount of 20-30 kgs./Ha. (lbs./acre) N is often recommended to fill in til the *Rhizobia* start functioning. Anyway, you'd never sidedress peanuts or other efficent N fixers with N; [1] get them to fix their own — it's far cheaper and usually makes the difference between profit and loss.

PROBLEM 7: 100 kgs./Ha. (lbs./acre) of 16-48-0 applied when corn is planted, followed by 150 kgs./Ha. (lbs./acre) of Urea (45-0-0) applied on the soil surface at knee high stage.

WHAT'S WRONG?:

1. He (she) is putting on a total of 83 kgs. (lbs.) of N in the 2 applications (16 + 67) which is an acceptable total rate. BUT remember that 1/3-1/2 of the total N should be put on at planting; only 16 kgs. (lbs.) are being put on in this case or about 20% of the total. That's too little. As a general rule, no less than 25-30 kgs./Ha. (lbs./acre) of N should be applied at planting or you may run into an N deficiency before sidedressing time.

2. The 150 kgs. (lbs.) dosage of Urea is OK BUT it's being left on the soil surface; up to 25-30% may be lost as ammonia gas (see p. 73) or it may be carried away by surface flow of water. Work it in about an inch deep to avoid this.

3. The soil may need K also.

PROBLEM 8: Miguel makes up a "starter" fertilizer solution for his tranplants by mixing a couple tablespoonfuls of Urea in a gal. of water and applying about 1 coffee cupful per transplant hole. No more fertilizer is used.

WHAT'S WRONG?: Urea won't help much as a starter solution; the transplants need a high P fertilizer like 12-24-12, 10-20-20, or 16-20-0 to help their roots perk up again. The starter solution isn't meant to replace the normal NP or NPK fertilizer application in solid form and only has enough nutrients for the first few days.

PROBLEM 9: Juan is planting mustard, Chinese cabbage, and radishes in the field and is applying 15-15-15 in a band directly below the seeds but separated by 1" (2.5 cms.) of soil. He's applying it at the rate of 1000 kgs./ha. (lbs./acre).

WHAT'S WRONG?:

1. Placing an NPK fertilizer directly below the seed is risky at anything but very low rates; when the soluble N and K salts dissolve, they move upward when the soil dries and may injure the seeds. You could be alright at 250 kgs./Ha., but seed and fertilizer should be separated by 2-3" (5-7.5 cms.).

2. 1000 kgs./Ha (lbs./acre) is way too high a rate of NPK, especially N (much will be lost by leaching). Cut it back to about 300-400 kgs./Ha.

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[1] Actually, an N sidedressing may be necessary if the plants show N hunger signs, but that should never happen under good management.

V. GETTING THE MOST OUT OF FERTILIZERS

Factors that Affect the Response You'll Get

1. Timing and Method of Application: Make sure you understand the basics of fertilizer application methods and timing.

2. The Right Nutrient Balance: If 2 or more nutrients are deficient simultaneously (very likely), adding only one may have little effect. Check out this fertilizer trial on corn in a soil where both N and P were low:

Treatment	Yield per acre	Yield Increase
None	4 bushels	----
N only	12	8
P only	21	17
N + P	58	54

In some cases, an excess of one nutrient relative to another can cause uptake problems:

A. A high ratio of potassium or ammonium to magnesium can cause a deficiency of Mg in susceptible crops like tobacco and pastures.

B. A high ratio of K to calcium may cause a Ca deficiency in peanuts.

C. Large applications of P can cause iron or zinc deficiencies in soils where they're at a borderline level.

D. A high ratio of Ca to Mg can cause Mg deficiencies.

E. Overliming a soil can cause micronutrient deficiencies (except for molybdenum).

F. Excess soluble copper and manganese can cause iron deficiencies and vice-versa. (Happens in very acid soils sometimes).

3. Type of Crop: Corn, sorghum, short strawed rice varieties, sugarcane, bananas, pastures, and most vegies are more likely to give good fertilizer returns than coffee, cacao, and most tree crops (unless they're suffering from a real deficiency). Soybeans and peanuts often respond better to residual fertility than to directly applied P and K.

4. Variety: Improved varieties and hybrids (if adapted to the area) usually give a much better response to fertilizer than native ones. In a fertilizer trial in India with

corn, a hybrid and a local variety were compared at the same fertilizer rate; the hybrid yielded 8000 lbs./acre and the native variety only 2000 lbs.

Whatever the variety, be sure it's adapted to your area (i.e. don't blindly use those free CARE seeds in the PC office - chances are that the variety isn't well suited to your area). Likewise, don't expect cool weather crops like spinach, potatoes, broccoli, celery, cauliflower, peas, carrots, beets, head lettuce, and turnips to yield well in hot weather.

5. Insect & Diseases: They'll easily wipe out profits if not controlled.

6. Weeds: They rob water, light, and nutrients and also harbor insects and diseases. Best time to control them is when they're tiny; sloppy or delayed weeding can easily cut yields by 50% or more.

7. Soil Limiting Factors: pH problems, poor tilth, hardpans, poor drainage, shallowness, etc. will all lower response; before advising a farmer on fertilizer use, check out his land - it could be a no-win situation.

8. Moisture and Temperature: Adequate water is vital for a full fertilizer response; fertilizer does increase drought resistance somewhat. Unusually high temperatures can hurt yields, especially if they occur at pollination time (i.e. corn, tomatoes).

Use the "Package" Approach!

You'll make far greater progress raising yields by introducing a "package" of improved practices rather than relying on fertilizer alone. The package approach not only markedly boosts yields compared to a one input strategy but also cuts the risk to the farmer. Improved practices have a remarkable way of interacting with each other; take a look at this trial on wheat in Mexico:

Treatment	Yield Increase
Irrigation	5%
Fertilizer	135%
Irrigation + fertilizer	700%

Any viable package must usually include an improved variety, proper plant spacing and population, fertilizer use, and control of insects, diseases, and weeds.

VI. COPING WITH FERTILIZER MATH

There's some math involved in using fertilizers; it's straight forward but takes some practice. We'll cover these 5 areas:

1. Converting fertilizer recommendations from an $N-P_2O_5-K_2O$ basis to actual kind and amount of fertilizer(s) needed.
2. Choosing the most economical fertilizer.
3. Mixing fertilizers.
4. Determining how much fertilizer is needed per plant, per length of row, or per area.
5. Converting fertilizer dosages from a weight to volume basis.

I. CONVERTING FERTILIZER RECOMMENDATIONS FROM AN $N-P_2O_5-K_2O$ BASIS TO ACTUAL KIND AND AMOUNT OF FERTILIZER(S) NEEDED

Fertilizer recommendations, especially those from soil tests, are often given in terms of the amount of N, P_2O_5, and K_2O needed per acre or hectare, etc. It's up to you to pick the kind and amount of fertilizer(s) needed to match the recommendation.

PROBLEM #1: Soil test results recommend that Angelita fertilize her corn like so:

(LBS. PER ACRE)
KILOGRAMS PER HECTARE

	N	P_2O_5	K_2O
At Planting:	40	50	0
At knee high stage:	60	0	0

If the local ag store has the following fertilizers on hand, which ones should he use, and how much will it take to cover one hectare?

Fertilizers Available

18-46-0	12-24-12	Urea (45-0-0)
16-20-0	14-14-14	0-0-60

SOLUTION:

Let's take the 40-50-0 planting recommendation first. The easiest approach is to pick the fertilizer whose $N:P_2O_5:K_2O$ ratio comes closest to that of the recommendation (40-50-0 = 1:1.25:0). You know right off that 12-24-12, 14-14-14, urea, and 0-0-60 won't work, which leaves only 18-46-0 and 16-20-0. 18-46-0 has a 1:2.55:0 ratio which is too high in P_2O_5; that would mean having to put on 102 kgs. (lbs.) P_2O_5 in order to supply 40 kgs. (lbs.) of N. 16-20-0 has a 1:1.25:0 ratio which is just what we're looking for.

To find out how much 16-20-0 is needed to supply 40 kgs. (lbs.) N and 50 kgs. (lbs.) P_2O_5, divide 40 by 16% (0.16) or 50 by 20% (0.2) which gives you 250 kgs. (lbs.). So, if Angelita applies 250 kgs. (lbs.) of 16-20-0 per hectare (acre) he'll supply the 40 kgs. (lbs.) N and 50 kgs. (lbs.) P_2O_5 called for by the recommendation.

Now what about the sidedress recommendation of 60 kgs. (lbs.) N? Urea is the obvious choice, since it's the only fertilizer on the list that has just N. To find out how much urea it takes to supply 60 kgs. (lbs.) per hectare (acre), divide 60 by 45% (0.45) and you'll get about 133 kgs. (lbs.).

You won't always be able to follow a recommendation exactly, since the right fertilizer might not be on hand. Anyhow, fertilizer recommendations aren't anywhere near 100% accurate. Do try to get within 15-20% of the amounts recommended though. If you have to put on extra P to supply enough K or vice-versa, don't worry; K, and especially P, aren't readily leached. Look at problem #2 below:

PROBLEM 2: Soil test results advise Ben to fertilize his tomatoes like so:

(LBS. PER ACRE) *1
KILOGRAMS PER HECTARE

	N	P_2O_5	K_2O
At transplanting:	60	100	40
Sidedressing every 4 weeks	40		

If the local ag store has the following fertilizers on hand, which ones should he use, and how much will it take to cover one hectare?

Fertilizers Available

16-20-0	14-14-14	13-13-20
10-20-10	18-46-0	Ammonium sulfate (20-0-0)

SOLUTION:

Let's take the transplanting recommendation first. Of the 3 NPK fertilizers above, 10-20-10 has the nutrient ratio closest to that of the recommendation. 500 kgs. (lbs.) of 10-20-10

*1. To save space, each problem is given in terms of kgs./Ha. and lbs./acre. Since there's only about a 10% difference between them, they can be used interchangeably for our purposes.

would supply 50-100-50 on a kgs./Ha. (lbs./acre) basis. That puts us a bit low on N and high on K_2O, but it's no big problem. The extra K won't leach much, and Ben can make the first sidedressing of N a few days early to make up for being slightly low on the transplanting application.

200 kgs. (lbs.) of 20-0-0 would supply 40 kgs. (lbs.) of N for a sidedressing. Ben could put on a bit more the first time (say 250 kgs. or lbs.) to make up for the 10 kg. (lb.) deficit at transplanting or he could put the first sidedressing on a bit earlier (like at 3 weeks).

II. CHOOSING THE MOST ECONOMICAL FERTILIZER

At times you'll find 2 or 3 different N sources available and will want to know which one is the best buy. When comparing different fertilizers, what counts is the cost per kg. or lb. of nutrient not the cost per sack.

PROBLEM: Which fertilizer below is the most economical source of N?:

		COST IN DOLLARS	
FERTILIZER	% N	PER 100 lbs.	PER 50 kgs.
Urea	45%	\$13.50	\$14.85
Ammonium nitrate	33%	\$11.55	\$12.70
Ammonium sulfate	21%	\$8.40	\$9.24

SOLUTION: Trick is to find the cost per lb. or kg. of N; a 100 lb. sack of urea has 45 lbs. N and a 50 kg. sack has 22.5 kgs. N so:

$$\frac{\$13.50}{45\text{ lbs.}} = 30¢/\text{lb. of N} \qquad \frac{\$14.85}{22.5\text{ kgs.}} = 66¢/\text{kg. of N}$$

Ammonium nitrate works out to 35¢/lb. of N or 77¢/kg. of N, and ammonium sulfate works out to 40¢/lb. of N or 88¢/kg. of N.

That makes urea the cheapest source of N in this case. Usually, the higher analysis fertilizer will be the cheaper due to lower shipping cost per unit of nutrient.

Other factors may be important: Even though ammonium sulfate is usually more costly per unit of N, it does supply sulfur and might be the best choice on a sulfur deficient soil unless Another sulfur bearing fertilizer was used at planting time. On the other hand, it's considerably more acid than urea in its long term effect on soil pH (see p. 77). Ammonium nitrate is a quicker acting N source than urea since half its N is in the readily mobile nitrate form; it might be the best choice where the crop is showing N deficiency symptoms or when sidedressing has been delayed.

CAUTION: You can't compare 14-14-14 and 10-20-10 on a cost per unit of nutrient basis. A 1:1:1 ratio fertilizer may give better results than a 1:2:1 fertilizer or vice-versa, depending on the soil and crop. Don't try adding up the lbs. or kgs. of N, P_2O_5, and K_2O per bag and dividing this into the cost; each of the nutrients has a different cost per lb. or kg. You can compare fertilizers with the same nutrient ratio (i.e. 5-10-5 and 12-24-12).

III. MIXING DIFFERENT FERTILIZERS

PROBLEM: Suppose you need a fertilizer with a 1:3:1 ratio, but the local ag store only has 14-14-14 and 0-21-0. How could you combine the 2 fertilizers to obtain a 1:3:1 ratio, and what would its formula be?

SOLUTION:

100 lbs. of 14-14-14 contains 14 lbs. each of N, P_2O_5, and K_2O; if you added another 28 lbs. of P_2O_5 using 0-21-0, you'd end up with a 1:3:1 ratio mix. Divide 28 by 21% and you'll find that 133 lbs. of 0-21-0 will supply the 28 lbs. of P_2O_5 needed.

	N	P_2O_5	K_2O
100 lbs. 14-14-14 =	14 lbs.	14 lbs.	14 lbs.
133 lbs. 0-21-0 =	0	28	0
233 lbs.	14	42	14

Hold on now, the formula of the mix is not 14-42-14; those 3 numbers refer to how much N, P_2O_5, and K_2O are in 233 lbs. of the mix, not 100 lbs. To get the true formula (i.e. lbs. of nutrients per 100 lbs. of fertilizer or kgs. of nutrients per 100 kgs. of fertilizer), you'd have to reduce the 14-42-14 figure down to a 100 lb. basis like so:

14-42-14 ÷ 2.33 = 6-18-6 (actual formula)

CAUTION: Not all fertilizers can be mixed!

Lime in any form should never be mixed with ammonium N fertilizers or urea; it reacts to form ammonia gas. Don't mix lime with the ammonium phosphates, superphosphates, or any mixed fertilizer containing P, because it will make part of the P insoluble.

The table on the next page shows the mixing compatibility of common fertilizers.

FERTILIZER MIXING GUIDE

	Potassium chloride	*Potassium sulfate*	*Ammonium sulfate*	*Sodium nitrate & potassium nitrate*	*Calcium nitrate*	*Urea*	*Single, triple superphosphate*	*Mono & Di-ammonium phosphate*	*Lime*
Potassium chloride				X	X	X			
Potassium sulfate				X	X	X			
Ammonium sulfate				X	X	X			0
Sodium nitrate & Potassium nitrate	X	X	X			X	X	X	
Calcium nitrate	X	X	X	X		X	0	0	X
Urea	X	X	X	X	X		X	X	X
Single & triple superphosphate				X	0	X			0
Mono- & Di-ammonium phosphate				X	0	X			0
Lime			0		X	X	0	0	

$\boxed{}$ = Fertilizers which can be mixed.

$\boxed{X}$ = Fertilizers which can be mixed only shortly before use.

$\boxed{0}$ = Fertilizers which cannot be mixed for chemical reasons.

IV. DETERMINING HOW MUCH FERTILIZER IS NEEDED PER PLANT, PER LENGTH OF ROW, OR PER AREA

Fertilizer recommendations are usually given in terms of so much per acre or per hectare; you and the farmer are more interested in knowing how much fertilizer to apply per plant, per length of row, or per area. Here's a relatively easy way to work it out:

A. AMOUNT NEEDED PER AREA

PROBLEM 1: (METRIC) Soil test results advise Miss Lee to apply 250 kgs. of 16-20-0 per hectare to her corn field at planting time. How much 16-20-0 should she buy if her field measures 20 x 40 meters?

SOLUTION: Easiest way is to set up a proportion; here's 2 ways:

WAY 1: Find the plot's area in sq. meters (20 x 40 = 800 sq. meters). A hectare has 10,000 sq. meters so:

$$\frac{800 \text{ sq. mts.}}{10{,}000 \text{ sq. mts.}} = \frac{X \text{ kgs.}}{250 \text{ kgs.}}$$

Cross multiply like so:

10,000 X = 200000 kgs.

ANSWER: X = 20 kgs. of 16-20-0 needed*1

WAY 2:

$$\frac{250 \text{ kgs.}}{10{,}000 \text{ sq. mts.}} = \frac{X \text{ kgs.}}{800 \text{ sq. mts.}}$$

10000 X = 200000 kgs.

ANSWER: X = 20 kgs. 16-20-0 needed

WAY 3: If you can't cope with proportions, try this approach: Find out what fraction of a hectare the field is, and then multiply that fraction by the kgs./hectare dosage like so:

The 20 x 40 meter field = $\frac{800}{10{,}000}$ ths of a hectare

$\frac{800}{10{,}000}$ X 250 kgs. = 20 kgs. 16-20-0 needed

---

*1. Fertilizer is usually packaged in 100 lb., 112 lb., or 50 kg. bags. Miss Lee is better off buying 50 kgs. and storing or sharing the excess, rather than buying it in lesser quantities (usually a lot more expensive).

PROBLEM 2: (ACRE, LB. BASIS) Tom is advised to broadcast 14-14-14 at 300 lbs. per acre on his stargrass pasture at the start of the wet season. How much fertilizer will he need to cover his 80 ft. x 100 ft. pasture?

SOLUTION: Easiest way is to set up a proportion; here's 2 ways:

WAY 1:

Find the plot's area: 80 x 100 = 8000 sq. ft.

An acre has 43,560 sq. ft., so:

$$\frac{8000 \text{ sq. ft.}}{43{,}560 \text{ sq. ft.}} = \frac{X \text{ lbs.}}{300 \text{ lbs.}}$$

Cross multiply like so:

43,560 X = 2,400,000 lbs.

ANSWER: X = 55 lbs. 14-14-14 needed

WAY 2: $$\frac{300 \text{ lbs.}}{43{,}560 \text{ sq. ft.}} = \frac{X \text{ lbs.}}{8000 \text{ sq. ft.}}$$

43,560 X = 2,400,000 lbs.

ANSWER: X = 55 lbs. 14-14-14 needed

WAY 3: If you can't cope with proportions, try this approach: Find out what fraction of an acre the field is, and then multiply that fraction by the lbs./acre dosage.

The 80 x 100 ft. field = $\frac{800}{43{,}560\text{ths}}$ of an acre

$\frac{800}{43{,}560\text{th}}$ X 300 lbs. = 55 lbs. 14-14-14

B. AMOUNT NEEDED PER LENGTH OF ROW

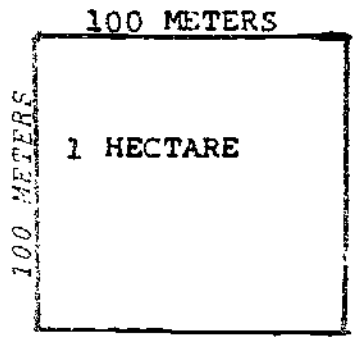
When you apply fertilizer in a band, you'll want to know how much to apply per row or per certain length of row.

PROBLEM 3: (METRIC BASIS) Moumen has been advised to apply 10-20-10 at 400 kgs. per hectare using the band method when he plants his Chinese cabbage (direct field planting). His field measures 10 x 15 meters with the rows spaced 50 cms. apart (100 cms. = 1 meter) and running the long way. How much 10-20-10 should he apply to each 15 meter long row?

SOLUTION:

WAY 1: Find out how many meters of row length a hectare would have with rows spaced 50 cms. apart; then find out the fertilizer dosage needed per meter of row length by dividing the dosage per hectare by total row length per hectare. Multiply the per meter dosage by 15, and you'll get the dosage needed for a row 15 meters long.

Base you calculations of a square hectare like so:



TOTAL ROW LENGTH PER HECTARE = number of rows per hectare X their length

To find the total row length in a hectare with 50 cm. rows:

50 cms. = 0.5 meters

Number of rows/Ha. = $\frac{100}{0.5}$ = 200 rows

Each row is 100 meters long so total row length is:

200 rows x 100 meters = 20,000 meters of row length

AMT. OF 10-20-10 NEEDED PER METER = $\frac{400 \text{ kgs.}}{20{,}000 \text{ mts.}}$ = 0.2 kgs. or 20 grams

AMT. NEEDED PER 15 METERS OF ROW = 15 x 20 grams = <u>300 grams</u>

<u>HELPFUL HINT</u>: Instead of having to deal with decimal places, start out by changing the original kgs./hectare dosage to <u>grams per hectare</u> by multiplying by 1000 (i.e. 400 kgs. x 1000 = 400,000 grams).

<u>WAY 2</u>: As in Way 1, start out by finding the total row length per hectare, and then set up a proportion like so:

$$\frac{15 \text{ mts. row length}}{20{,}000 \text{ mts. row length}} = \frac{X \text{ grams}}{400{,}000 \text{ grams}}$$

Cross multiply and you'll get:

20,000 X = 6,000,000 grams

X = 300 grams per 15 mts. of row length.

<u>WAY 3</u>:

$$\frac{15 \text{ mts. row length}}{20{,}000 \text{ mts. row length}} \times 400{,}000 \text{ grams} = 300 \text{ grams}$$

WAY 4: Find out how much fertilizer is needed on the area involved (in this case, 150 sq. meters):

$$\frac{150 \text{ sq. meters}}{10{,}000 \text{ sq. meters}} \times 400 \text{ kgs.} = 6 \text{ kgs.} = 6000 \text{ grams needed on the 10 x 15 meter plot.}$$

Then find out how many rows the plot has by dividing plot width by row spacing:

$$\frac{10 \text{ meters}}{0.5 \text{ meters}} = 20 \text{ rows}$$

Finally, divide the plot dosage by the number of rows:

$$\frac{6000 \text{ grams}}{20 \text{ rows}} = 300 \text{ grams 10-20-10 per 15 meter row}$$

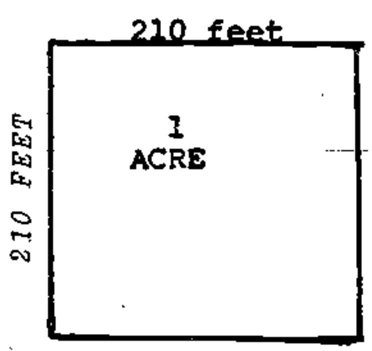
AN IMPORTANT POINT!: As long as you know the fertilizer dosage in terms of amount per hectare, you don't need to know how big Moumen's plot is. All you need to know is the row spacing. However, if you want to know how much fertilizer he'll use on his plot, then you need its dimensions.

PROBLEM 4: (ACRE, LB. BASIS) Pora is advised to apply 250 lbs. per acre of 16-20-0 in a band when she plants her grain sorghum. She tells you her rows will be 120 ft. long and 3 ft. wide and wants to know how much 16-20-0 to apply per row.

SOLUTION:

WAY 1: Since the dosage is given in lbs./acre, find out how many feet of row length an acre would have with rows 3 ft. apart; then find out how much fertilizer is needed per foot of row length by dividing the per acre dosage by total row length per acre. Finally, multiply by 120 to find out how much fertilizer is needed for a row 120 ft. long.

Base your calculations on a square acre like this:



(Actually, an acre is closer to 209 ft. on a side, but it's much easier using 210', and the error is very tiny.)

TOTAL ROW LENGTH PER ACRE = number of rows/acre X their length

Total row length/acre = number of rows/acre X their length

Number of rows/acre = $\frac{210 \text{ ft.}}{3 \text{ ft.}}$ = 70 rows

Each row is 210 ft. long so: 70 rows x 210 ft. = 14,700 ft. of row length per acre

Now find the amount of 16-20-0 needed per foot of row, but first convert the 250 lbs. to ounces to avoid messing with fractions of a pound. 250 lbs. x 16 = 4000 ounces

$$\frac{4000 \text{ oz.}}{14{,}700 \text{ ft.}} = 0.27 \text{ oz./ft. of row}$$

120 X 0.27 oz. = 32.5 oz. of 16-20-0 per 120 ft. of row

<u>WAY 2</u>: As in Way 1, first find the total row length per acre, and then set up a proportion like so:

$$\frac{120 \text{ ft. row length}}{14{,}700 \text{ ft. row length}} = \frac{X}{4000 \text{ oz.}}$$

14,700 X = 480,000 oz.

X = 32.5 oz. 16-20-0 needed per 120 ft. row

<u>WAY 3</u>:

$$\frac{120 \text{ ft. row length}}{14{,}700 \text{ ft. row length}} \times 4000 \text{ oz.} = 32.5 \text{ oz.}$$

<u>AN IMPORTANT POINT!</u>: Note that you didn't need to know the size of Pora's field to work this problem. All you need is the <u>dosage per acre</u> and his <u>row spacing</u>. As long as her rows are 3 ft. apart and she applies 32.5 oz. of 16-20-0 per 120 ft., she'll be applying 250 lbs. per acre no matter what her field size or shape. In this case, Pora's field size is needed only for figuring out how much total fertilizer she'll need.

IV. <u>AMOUNT NEEDED PER PLANT (OR PLANT GROUP)</u>

When using the half-circle or hole method of placement, the farmer will want to know how much fertilizer is needed per plant (or group of plants if in a "hill"). The trick is to calculate the number of plants you'd have in a hectare or acre, etc. and then divide this into the fertilizer dosage per hectare, acre, etc.

As in the last section, you're better off converting kgs. to grams and lbs. to oz. right at the start to avoid lots of decimal fractions.

PROBLEM 5: (METRIC BASIS) Soil tests advise Lam to apply 600 kgs. of 12-24-12 per hectare when he transplants his tomatoes; his rows are 1 meter apart with 80 cms. between plants in the row. He'll use the half circle method and wants to know how much 12-24-12 he should apply per plant.

SOLUTION:

Base your calculations on a square hectare (100 meters x 100 meters.

$$\text{AMT. OF FERTILIZER/PLANT} = \frac{\text{Fertilizer Dosage/Hectare}}{\text{Rows/Hectare} \times \text{Plants/Row}}$$

Rows/hectare = $\frac{100 \text{ meters}}{1 \text{ meter}}$ = 100 rows (each one is 100 mts. long)

Plants/row = $\frac{100 \text{ meters}}{0.8 \text{ mts.}}$ = 125 plants

125 plants/row x 100 rows = 12,500 plants/hectare

600 kgs. 12-24-12 = 600,000 grams

$\frac{600,000 \text{ grams}}{12,500 \text{ pls.}}$ = 48 grams 12-24-12 per plant

PROBLEM 6: (ACRE, LB. BASIS) Suheyla is advised to apply 300 lbs./acre of 14-14-14 at corn planting time. She'll plant 3 seeds/hole, space her rows 40 inches apart, and make the seed holes every 24 inches in the row. She is going to make a separate hole for the fertilizer next to each seed hole and asks you how much 14-14-14 each fertilizer hole should receive.

SOLUTION: (Use a square acre of 210 ft. x 210 ft.)

Find out how many seed holes an acre would have at this 40" x 24" spacing and divide that into the per acre fertilizer dosage.

seed holes/Acre = rows/acre x seed holes/row

rows/acre = $\frac{210 \text{ ft.}}{3.33 \text{ ft.}}$ = 63 rows (P.S. 42" = 3.33 ft.)

seed holes/row = $\frac{210 \text{ ft.}}{2 \text{ ft.}}$ = 105 seed holes/row

63 rows x 105 seed holes/row = 6615 seed holes/acre

300 lbs. x 16 = 4800 oz.

$\frac{4800 \text{ oz.}}{6615 \text{ seed holes}}$ = about 3/4 oz. 14-14-14 per seed group

Mixing Acres and Centimeters: No problem since an acre is close to 4000 sq. meters; if spacings are given in meters and centimeters, base your figuring on a 50 x 80 meter acre.

A Special Note on the Central American "MANZANA"

In most of Central America, the "Manzana" (1.73 acres or 0.7 hectares) is the standard unit of land measure. It contains 10,000 sq. "varas" (one vara = 32.8") or about 7000 sq. meters. Here's a couple tips for working with fertilizer recommendations on a lbs./manzana basis:

1. If row spacings and plant distances are in terms of "cuartas" (4 cuartas = 1 vara) and varas, use a square manzana with 100 vara sides for determining row length/mz. or plants/mz. For example, if Juan spaces his corn rows 5 cuartas apart, he'd have 8000 varas of row length per manzana (80 rows x 100 varas).
2. If row spacings and plant distances are in terms of cms. or meters, use a rectangular manzana measuring 70 x 100 meters. For example, if Themba plants 2 corn seeds per hole with 50 cms. between holes in the row and 1 meter between rows, he'd have 14,000 seed holes per manzana (140 holes/row X 100 rows).

V. CONVERTING FERTILIZER DOSAGES FROM A WEIGHT TO VOLUME BASIS

It's not much help telling your farmers to apply so many grams or ounces of fertilizer per length of row or per plant. They'll want to know the dosage in terms of tablespoonfuls, handfuls, or other volume measurement like a tuna fish can or juice can. The different fertilizers vary a lot in their weight per volume or weight in relation to water (1 c.c. of water weighs 1 gram, 1 liter of water weighs 1 kilo, 1 U.S. gal. of water weighs 8.3 lbs.).

The most accurate way to convert fertilizer dosages from a weight to volume basis is to use the local pharmacy's or post office's scales to determine the density of the particular fertilizer. If no scales are available, use the table below, although a fertilizer's density will vary with the brand.

FERTILIZER	APPROX. WEIGHT OF 1 Level Tbs. (15 c.c.)	100 c.c.	1 Cup (8 fl. oz.)
Ammonium sulfate & Superphosphate	0.6 oz., 17 g.	118 g.	9.5 oz., 270 grams
NP, NPK fertilizers, potassium chloride	0.5 oz., 14 g.	100 g.	8.0 oz., 225 g.
Urea & ammonium nitrate	0.4 oz., 11 g.	80 g.	6.5 oz., 185 g.

VII. FERTILIZER GUIDELINES FOR SPECIFIC CROPS

This section gives specific fertilizer guidelines for the following crops:

Corn (maize)	Cassava (manioc, yuca)
Sorghum (grain & forage)	Sweetpotatoes
Rice	Potatoes
Beans	Vegetables
Soybeans	Pastures
Peanuts	Coffee
	Bananas

CORN (MAIZE)

Some Important Facts on Corn You Need to Know

Depending on variety and temperature, corn reaches physiological maturity (i.e. the kernels cease accumulating starch, protein, fat, and minerals) in about 90-130 days in the 0 - 3000 ft. zone of the tropics but may take up to 8-12 months at high elevations (7000 ft. on up). At this stage, kernel moisture has dropped to around 30-35% which is still too high for mold-free storage. Most small farmers let the corn continue drying on the stalk in the field for several weeks before harvesting. Some supplemental drying by sun or grain dryer may still be needed; a 12-13% moisture content is necessary for safe storage of shelled grain, while ear corn can be put into a properly designed crib at 24-28% moisture. Storage insects like weevils and grain moths are an ever-present problem and can be controlled by fumigation or coating kernels with special insecticides.

A large ear of corn may have 1000 kernels, but a normal ear has about 500-600. The shelling percentage is about 80% (70 lbs. of ear corn yields about 56 lbs. or 1 bushel of shelled grain).

Growth stages: In the 0-3000 ft. zone of the tropics, it takes about 50-70 days from seedling emergence to tasseling and about 50-60 days from tasseling to maturity (varies with variety and temperature). About 1-2 days before pollen shed, the tassel is thrust out of the leaf whorl; pollen shedding begins 2-3 days before the silks emerge from the ear and continues for 5-8 days. Corn is cross-pollinated (95% or more of the kernels on a cob are pollinated by other plants). Under favorable conditions, all the silks will emerge within 3-5 days, and most will be pollinated immediately. Shortage of pollen is rarely a problem; poor ear fill or skipped kernels are almost always due to delayed silk emergence or ovule abortion, both of which are caused by drought, overcrowding, or a shortage of N or P.

Pollination is a very critical time with a high demand for water and nutrients, especially N. Nutrient and water use is heavy from about 3 weeks before to 3 weeks after pollination.

Yields: Average yields of shelled grain (14% moisture) under varying conditions are shown below:

	Lbs./Acre	Kgs./Hectare	Lbs./Manzana
Top farmers in U.S. Corn Belt	9000 - 12,000 +	10,000-13,500+	15,500 - 21,000
U.S. average	5000	5500	8500
Average yield in developing countries	850-1250	950-1400	1500-2200

Fertilizer Response

When starting from a low base like 850-1250 lbs./acre,*1 yields of shelled grain should increase by roughly 50-100 lbs. for each 2 lbs. of N + 1 lb. of P_2O_5 applied *if* moisture and other nutrients are adequate and there are no serious limiting factors as far as insects, diseases, weeds, pH, soil drainage, and depth; use of a suitable improved variety or hybrid and an adequate plant population are important. This yield response formula applies to NPK rates within the "low", "medium", and "high" ranges of the table on p. 89.

EXAMPLE: You set up a fertilizer demo on corn; the fertilized plot receives a total of 80 lbs. N, 40 lbs. P_2O_5, and 40 lbs. K_2O and yields 2500 lbs./acre, while the unfertilized plot yields 1500 lbs./acre. Should you be satisfied with the response?

SOLUTION: According to the response formula, 80 lbs. N and 40 lbs. P_2O_5 should have increased the yield by 2000-4000 lbs./acre for a total yield of 3500 (i.e. 1500 + 2000) lbs. to 5500 (1500 + 4000) lbs./acre.

*1. On a metric basis, each 2 kgs. N + 1 kg. P_2O_5 should increase yields by 50-100 kgs. of shelled grain.

Since only a 2500 lbs./acre yield was obtained, one or more limiting factors were present.

N-P-K Needs

Use the table on p. 89 as a guide. Corn and other grass family crops like sorghum, rice, wheat, and pasture grasses are more efficient potassium extractors than most other crops. On many loamy to clayey soils of volcanic origin, little or no K may be needed, but send in a soil sample to make sure. Studies have shown that corn utilizes banded or hole placed P (see p.84) efficiently up to about 50-60 lbs./acre (kgs./Ha.) of P_2O_5.

Sulfur, Calcium, and Magnesium: Sulfur deficiencies are rare in corn but most likely in coarse textured soils under high rainfall, in volcanic soils, or in cases where low sulfur fertilizers have been used for several years (see p.76). Magnesium deficiencies are uncommon also except in very acid soils (see p. 47). Calcium deficiencies are very rare and only occur in very acid soils (see p.47).

Micronutrients: Except for zinc, corn isn't especially susceptible to micronutrient deficiencies (zinc, copper, iron, manganese, boron, molybdenum). Such deficiencies are most likely to occur above a pH of 6.8 (except for Mo) or in sandy or organic soils (peats, mucks). Large applications of P may lower zinc uptake below the critical level in low zinc soils. To confirm zinc deficiency, spray 10-20 plants with a solution of 1 teaspoon zinc sulfate in one gallon of water plus about a teaspoon of liquid detergent as a wetting agent. If zinc is deficient, new leaves will be a normal green when they emerge. See p. 82 for ballpark micronutrient rates.

Hunger Signs in Corn: See pp. 155-159.

Application Guidelines for Corn

Apply 1/3-1/2 of the total N at planting along with all the P and K; sidedress the remaining N at knee-high stage. Under high rainfall, especially with sandy soils, apply no more than 1/3 the total N (but at least 25 lb./acre) at planting; if leaching losses are likely to be high, 2 N sidedressings may be needed (1/3 of total N at knee high, 1/3 of total N at silking). Leaching losses of K can be a problem under these conditions, and you may want to make 2 applications (at planting and knee-high).

1st Application: Use an NP or NPK fertilizer with a ratio that allows you to put on all of the P and K but only 1/3-1/2 of the total N. Apply the fertilizer at planting time using one of the band or hole methods on p. 84. Don't broadcast the fertilizer. If working with furrow irrigated soils, check over the placement guidelines on p.89 .

Sidedressing: When making one N sidedressing, knee-high stage is the best time. Use a straight N fertilizer like urea, ammonium nitrate, or ammonium sulfate. Ammonium nitrate is ideal when sidedressing has been delayed or to cure N hunger signs since half its N is already in the mobile nitrate form; however, leaching losses might be higher than for other ammonium type fertilizers. Deep placement of the sidedressed N is not only unnecessary but might result in pruning the roots. Try to get it down about ½-1" deep (just enough to prevent it from being washed away by heavy rains if the ground is sloped); also, urea will lose some N as ammonia gas unless covered by a bit of soil. By knee high stage, the roots have usually reached the row middles, so placement of the fertilizer right down the row middle is fine and just as effective as closer placement. When using furrow irrigation, the fertilizer must be placed below the high water line to avoid the N being carried upward and away from the roots by capillary water movement.

Use the "Package Approach"!

Don't expect fertilizer use alone to markedly increase corn yields. It usually takes a "package" of improved practices to do the trick, and this includes use of a suitable improved variety or hybrid, control of insects, weeds, and diseases, the right plant population and spacing, and good storage practices.

Some Guidelines for Plant Population & Spacing

	RECOMMENDED PLANT POPULATIONS	
	Per Acre	Per Hectare
Low fertility and/or moisture	5000 - 10,000	12,500 - 25,000
Adequate fertility & moisture	14,000 - 18,000	35,000 - 45,000
Adequate moisture, high fertility (100+ lbs. N/acre), top management, and use of an improved variety or hybrid adapted to high populations.	19,000-24,000	47,000-60,000

To achieve these populations, you'll need to overplant by 15-20% to allow for germination losses, etc.

Corn has a lot of buffering ability when it comes to population. A population 40% below optimum may only lower yields by 15-20% or so, since the plants respond to the greater amount of space by producing more and/or larger ears.

Ear Size is a good indicator of how adequate the plant population was for the growing conditions. Dry, husked ears weighing more than 10-11 ounces (280-300 grams) usually mean that plant population was too low and that yields might be 10-20% higher. However, overly high plant populations increase lodging (tipping over) and are likely to produce weak stalked plants with small ears. Ear size of prolific varieties (those producing more than one ear per plant) won't vary as much with population as with single eared varieties; instead, the number of ears per plant will decrease as population increases.

Plant Spacing: Many small farmers plant 4-6 seeds per hole with the holes a yard or more apart. This greatly cuts down the labor of hand seeding, but yields suffer since the plants compete for water, light, and nutrients within a small area. A good compromise is to plant 2 seeds every 16-18" (40-45 cms.) or 3 seeds every 24-27" (60-68 cms.) with rows 36-40" apart. That'll give you about 15,000-18,000 plants/acre (37,000-45,000/Ha.) as a final stand.

GRAIN & FORAGE SORGHUM

Grain sorghum plants look a lot like corn when young; the plant produces semi-round seeds about an 1/8" size on a seed head rather than an ear. Sorghum is more resistant to drought and high heat than corn yet also more tolerant of poor drainage. It owes its drought resistance to an extensive root system, a relatively small leaf area per plant, and its ability to go dormant during periods of moisture stress. Grain sorghum varieties are usually short (3-5 ft.) while forage types are taller and more leafy with sweeter stalks.

Grain sorghum matures in about 90-120 days in the 0-3000 ft. zone of the tropics. Some native varieties are sensitive to day length and won't mature until the shorter days of October (April below the Equator) no matter how early they're planted.

Forage sorghums and many grain sorghums will produce several cuttings of forage or grain from one planting; new stalks will sprout from the base of harvested plants.

Leaves and stalks of young sorghum plants contain poisonous hydrocyanic acid (prussic acid). Cattle and sheep are very susceptible to poisoning though horses and pigs seem to be immune.

Grain sorghum yields approximate those of corn when moisture is adequate, though high rainfall and humidity promote grain rot (using open headed varieties helps). Sorghum will outyield corn considerably under low moisture conditions.

During the 6 month rainy season, small farmers in El Salvador have harvested 3 cuttings of forage sorghum (or sorghum-sudan crosses) for a total wet weight yield of 43 tons/acre (75 tons/manzana, 96000 kgs./Ha.). Best time to harvest in terms of nutritive value and yield is at the early heading up to the soft dough stage.

Fertilizer Guidelines

The NPK needs of sorghum are similar to those of corn. Sorghum is especially sensitive to iron deficiencies which are most common above a pH of 6.8. Deficiencies can be treated by applying 10-15 lbs. of ferrous sulfate per acre (10-15 kgs./Ha.) in 20-50 gals. of water (use a wetting agent to enhance uniform coverage) per acre 10-15 days after seedling emergence; repeat in about 10 days if symptoms persist. See p.155 for hunger signs in sorghum.

Sorghum seeds and seedlings are more easily burned by fertilizer than corn so avoid fertilizer contact with seed. Follow the NPK guidelines on p. 89 , and use the same application methods as for corn. If harvesting more than one cutting from a single planting, apply all the P and K at planting time along with about 30-50 lbs. N/acre; sidedress another 50-70 lbs. N/acre 30 days later; after each cutting apply 30-50 lbs. N/acre followed by a sidedressing of 50-70 lbs. N/acre 25 days later.

RICE

Rough rice (includes the hull) yields average about 5500 lbs./acre (6000 kgs./Ha.) in the developed countries but only about 1400 lbs/acre (1550 kgs./Ha.) in the developing countries. Yet yields as high as 11000 lbs./acre (12,500 kgs./Ha.) have been obtained in both areas.

Rice matures in about 110-150 days, though some native varieties may take 6 months or more. 100 lbs. of rough rice after milling will yield: 64-68 lbs. whole and broken kernels, 20 lbs. hulls, 10-13 lbs. rice bran, and 3-4 lbs. rice polish (a mixture of the inner bran layer with some of the starchy interior plus part of the germ).

Lowland (Flooded) vs. Upland (Dryland) Rice

Dryland rice relies entirely on rainfall or periodic irrigation for moisture and is grown mainly on clayey soils with slow subsurface drainage where a high moisture content can be maintained. However, flooded rice yields are usually 50-60% higher than dryland yields because:

1. Flooding provides a more ideal environment for the roots.
2. It increases the availability of certain nutrients, especially phosphorus.
3. It helps control weeds.

The catch is that flooded rice production requires level land, plenty of water, a system of canals and dikes, and soils impermeable enough to maintain a 2-6" layer of water over them without excessive leaching.

High N Response vs. Low N Response Varieties

Nearly all the native tropical varieties of rice are low N response varieties which are tall growing (over 5 ft.) and leafy; they respond to increasing rates of N by growing still taller and producing more tillers (stems from the same plant). This causes lodging (tipping over) plus a mutual competitive shading of the added tillers which cuts down the number of seed heads. Such varieties seldom respond well to more than 20-30 lbs. N/acre.

Most of the temperate zone varieties are high N responders and are short strawed (3-4½ ft.) with a high number of seed producing tillers. Many of the improved tropical varieties are crosses between the 2 types and show a profitable response to up to 100 lbs. N/acre or more without lodging.

Transplanting vs. Direct Planting

In the tropics, rice is most commonly started out in a nursery seedbed and then transplanted to the field 20-30 days later. Transplanting gives the plants a jump on weeds, makes it easier to raise healthy seedlings in a confined space, and allows optimum plant spacing in the field. On the other hand, direct seeding speeds up maturity by 7-10 days and eliminates the labor involved in caring for and transplanting the seedlings. However, direct seeding allows more opportunity for rat and bird damage and makes weeding difficult if the broadcast method of seeding is used (unless herbicides are available and cost feasible).

Nutrient Needs of Rice: N needs depend on whether a low N or high N response variety is used. The P needs of rice are unusually low compared with other grain crops; dryland rice often gives more of a response to fertilizer P than flooded rice since flooding increases P availability. P_2O_5 rates on flooded soils seldom exceed 40 lbs./acre (kgs./Ha.).

Responses to added potassium are most likely on sandy soils. The rice straw itself contains about 80-90% of the plant's total K so returning the residues to the field is a good way to recycle K (this is also true of most crop residues). Secondary and micronutrient deficiencies are uncommon, although iron hunger is occasionally seen above a pH of 7.0.

Placement and Timing of Fertilizer

Dryland Rice: Apply an NP or NPK fertilizer at or shortly before planting (dryland rice is direct planted). If applied before planting, it can be broadcast and then harrowed or plowed into the soil. When applied at planting, it can be placed in a band slightly below and to the side of the seed row. Deep placement of P and K isn't necessary with rice since it has a lot of roots very near the surface. Apply about a third of the N at planting and sidedress the rest about 50 days later. Total N rates can go as high as 100 lbs./acre (kgs./Ha.) when using improved varieties.

Transplanted Flooded Rice: Most seedling nurseries aren't fertilized, but you can try applying about 40 grams 12-24-12 or equivalent per sq. meter (broadcast it and rake it in lightly).

An NP or NPK fertilizer should be broadcast and harrowed in shortly before transplanting. Urea or an ammonium N fertilizer should be used and placed about 2" deep to avoid N loss by denitrification or leaching (see below). Most of the N can be applied at planting, followed by the remainder about 60 days before harvest; for short maturity varieties that are N responsive, all the N can be applied at planting on clayey soils.

Placement of N under Flooded Conditions: It's important to remember that urea or an ammonium form of N should be used with flooded rice and placed about 2" deep to avoid losses by denitrification (conversion to nitrogen gas) or leaching. That's because a flooded soil has two layers: one with oxygen (aerobic) and one without oxygen (anaerobic). The aerobic layer is confined to the top quarter inch of soil, and below that is the far larger anaerobic layer. Ammonium forms of N and urea (which gets converted to ammonium) are held by the clay and humus particles; nitrate N is readily leached. If ammonium N or urea is placed in the aerobic zone, there's enough oxygen for soil bacteria to convert the fertilizer into nitrate (NO_3^-). The nitrate then leaches down into the anaerobic zone where oxygen hungry bacteria steal the oxygen (O) from the NO_3^- and convert it into nitrogen gas (N_2) which is lost to the atmosphere. However, if the ammonium N or urea is originally placed in the anaerobic zone, it'll remain as ammonium and be kept from serious leaching; the ammonium N

(NH_4^+) doesn't contain oxygen, so there's no danger of denitrification.

When applying N at planting time to direct seeded lowland rice or at transplanting time to lowland rice, the soil should be flooded within 3-4 days to prevent excessive conversion of ammonium N to nitrate due to non-flooded aerobic conditions.

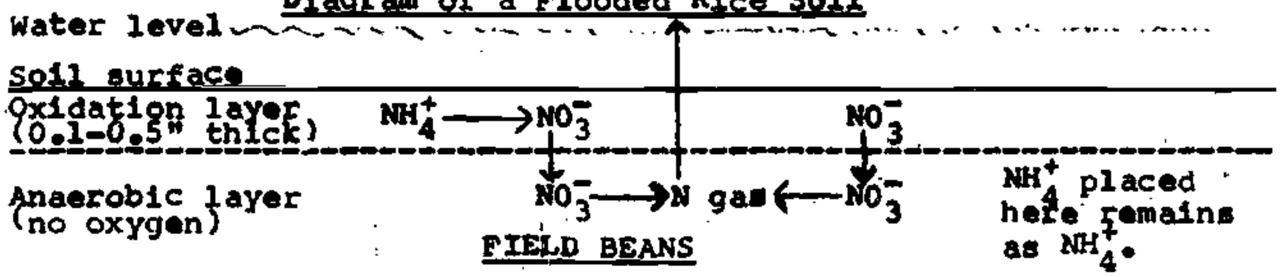
Numerous studies have shown that broadcasting N fertilizer over the water is only about half as effective as placing it a couple inches deep in the anaerobic zone.

An important point about urea is that it's mobile until it's been converted to ammonium (takes a couple days) and this requires oxygen; hold off reflooding for a couple days after application to allow the conversion to take place.

In very acid, highly leached soils low in iron, ammonium sulfate may cause a toxic accumulation of sulfide under flooded conditions.

Fertilizer use on flooded rice is pretty technical as you can see, so be sure and consult reliable sources of info in your country.

Diagram of a Flooded Rice Soil



FIELD BEANS

Field beans (kidney, navy, pinto, etc.) and other types like cowpeas and mung beans contain around 22-26% protein and are an important source of this nutrient in most Peace Corps countries. Average yields in most developing countries are around 600 lbs./acre (650 kgs./Ha.) but this could be doubled or tripled using improved practices and varieties.

Although they're legumes, beans vary a lot in their nitrogen fixing ability. Cowpeas and mung beans are fairly efficient as long as the proper strain of Rhizobia bacteria is present in the soil; only around 25 lbs./acre (kgs./Ha.) of N is usually recommended as an at-planting application with no further sidedressings. Field bean types are less efficient N fixers, and rates of 40-60 lbs. N/acre (kgs./Ha.) are usual (in high rainfall areas sidedress about half the N about a month after planting). Occasionally, it may be necessary to innoculate cowpea or mung bean seed with the proper Rhizobia (see peanuts) if cowpea Rhizobia family crops haven't been grown on the soil within 3 years (i.e. mung beans, peanuts, cowpeas, lima beans, Crotalaria).

Phosphorus rates for beans are usually in the 30-40 lbs. P_2O_5/acre (kgs./Ha.) range, while potassium rates range from 0-40 lbs./acre (kgs./Ha.) of K_2O.

Beans are sensitive to manganese and zinc deficiencies which are most likely to occur at pH's above 6.8. See p. 82 for control. On the other hand, manganese toxicity becomes increasingly likely at pH's below 5.5.

When applying an NP or NPK fertilizer at planting, use the band method but avoid fertilizer contact with the seeds (beans are especially sensitive to "burn").

SOYBEANS

Mature, dry soybeans range from 14-24% in oil and 30-45% in protein (usually, the higher the oil content, the lower the protein). In the Western Hemisphere, soybeans are grown mainly for their oil which is used in cooking, margarine, and industry. Many of the high yielding varieties are also high in oil and not very palatable for humans. The soybean meal which remains after oil extraction (done by crushing or with solvents) is an important high protein feedstuff used in pig and poultry rations. Raw soybeans have a trypsin inhibitor (trypsin is an enzyme needed for protein digestion) which first must be deactivated by heating before they can be used for food or feed; this is done during the manufacture of soybean meal.

Soybean varieties are extremely photosensitive in that 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 small, and yields will be poor. Many soybean varieties grown in the tropics come from the Southern U.S. since day length differences aren't serious.

The average soybean yield in the U.S. is about 1800 lbs. acre (2000 kgs./Ha., 3000 lbs./manzana). Yields of 2500-3000 lbs./acre are common. A realistic yield goal for the tropics would be about 1800-2400 lbs/acre (2000-2700 kgs./Ha.).

Fertilizer Guidelines

Soybeans are an efficient N fixing legume. Fertilizer N usually gives no response to properly nodulated soybeans.

Some sources recommend applying a small amount of N fertilizer at planting (25 lbs./acre) to get the plants off to a good start until the Rhizobia start functioning but this isn't universal.

Soybeans grow best within a pH range of 6.0-7.0. More acid soils depress the activities of the soybean strain of Rhizobia and can also cause manganese and aluminum toxicities as well as molybdenum deficiencies (Mo is also needed by the Rhizobia). Above a pH of 7.0, P and micronutrient deficiencies (except Mo) are more likely.

Soybeans respond well to P and K on soils low in these nutrients; response is much less likely if soybeans follow a well fertilized crop. Rates of 20-60 lbs./acre (kgs./Ha.) of P_2O_5 are common. Soybeans are heavy K users and rates range from 30-100 lbs./acre (kgs./Ha.) of K_2O. Soil test to get a better idea.

P and K should be applied in a band at planting time about 2" (5cms.) below and 2" to the side of the seed. Soybeans are very sensitive to "burn" so don't place fertilizer with the seed (it will also kill the Rhizobia on innoculated seed).

Although sensitive to manganese toxicity (common below a pH of 5.5), soybeans often suffer manganese deficiencies at pH's above 6.5. Best way to control Mn deficiency is to spray the plants with 10 lbs. of manganese sulfate in 15-40 gals. of water per acre. You can apply 25 lbs./acre of manganese sulfate mixed with the P and K you apply at planting in a band. Use a wetting agent when applying Mn to the leaves (like 2 tablespoons liquid detergent per 4 gallon backpack sprayer tankful).

Molybdenum is needed by both the plants and the Rhizobia, but deficiencies only occur on acid soils. Liming the soil to a pH of 6.0 will usually correct problems. Instead of liming, the seed can be treated with molybdenum at the same time it's innoculated. Add 1/2 oz. (15 grams) of sodium or ammonium molybdate to 1 cup (240 c.c.) hot water and then add a few drops of syrup or molasses. Cool and then mix the solution with 60 lbs. of seed; then add the innoculant and plant the seed as soon as possible.

Magnesium deficiencies are only likely below a pH of 6.0. Liming with dolomitic limestone to a pH of 6.0-6.5 will correct problems. Don't raise the pH above 6.5 or you may promote manganese deficiencies.

Seed Innoculation: Soybeans require a very specific strain of Rhizobia bacteria. Unless soybeans have been grown on the same soil within a year or two and were known to be properly nodulated (see under peanuts), the seed should be innoculated with soybean Rhizobia. The innoculant is a dark colored dried powder which contains the living bacteria and comes in a sealed package (check the expiry date). The seed is placed in a basin and moistened with water to help the innoculant stick (adding a bit of molasses helps too), and the correct amount is mixed with the seed. The seed should be planted within a few hours; avoid exposing it to sunlight for long or the bacteria may be killed. Be sure the innoculant you use is specifically for soybeans. You can examine plants for proper nodulation about 3-4 weeks after planting (see under peanuts).

PEANUTS

Mature, shelled peanuts contain about 40-48% oil and 25-30% protein. One ton of cleaned but unshelled peanuts yields about 530 lbs. of oil, 820 lbs. of meal, and 650 lbs. of shells. Peanuts mature in 3-5 months and prefer well drained soils that aren't too clayey (the peanut "pegs" have difficulty entering hard clayey soils). Average yields in Peace Corps countries are about 600-1000 lbs./acre (700-1100 kgs./Ha.). With improved practices, yields of 1500-2000 lbs./acre (1700-2200 kgs./Ha.) are very feasible and can run as high as double that.

Fertilizer Needs and Application Methods

The peanut is not really a nut but a legume (seed in a pod). If the right strain of Rhizobia is present, they require little or no N. Studies have shown that a light dose of 20-30 lbs. N per acre (kgs./Ha.) at planting helps the young plants along during the period when the Rhizobia haven't yet started to fix N.

Seed Innoculation: Seed should be innoculated (see under soybeans) if peanuts, cowpeas, lima beans, or crotalaria haven't been grown on the land within 3 years. Be sure to use the right strain of innoculant.

Checking for Proper Nodulation: Carefully remove the roots of plants at least 3 weeks old from the soil and look for clusters of fleshy nodules (up to the size of small peas) especially on the tap root; slice a few open and an interior reddish color means they're actively fixing N.

Soil pH: Peanuts grow best within a pH range of 5.5-6.5. Higher pH's increase the chance of manganese deficiencies, while very acid conditions may cause manganese and aluminum toxicities and magnesium deficiencies. Use dolomitic limestone if liming is needed and don't go above pH 6.5.

P and K: Peanuts have an unusual ability to utilize residual fertilizer from preceding crops and don't often give profitable responses to direct applications of P and K unless soil levels are very low. There's good evidence that high K levels in the podding zone actually hurt yields by increasing. In short, peanuts give a fickle response to P and K. If planning to apply a small amount of N at planting (20-30 lbs./acre), try using 16-20-0 at 150 lbs./acre (kgs./Ha.) on a small area as a test (or mix some superphosphate with the N fertilizer). Don't hold your breath waiting for a response. Band apply it.

Calcium: This crunchy legume is one of the few crops having a high requirement for calcium as a nutrient. Light green plants plus a high % of unfilled shells (called "pops") may indicate Ca hunger. Gypsum (calcium sulfate) is the usual remedy; it's much more soluble than lime and also has no effect on pH. The nuts themselves won't develop in a soil layer deficient in Ca even though enough Ca is available to the roots below. That means you should dust the gypsum in a 15" wide band directly over the plants so it'll be leached down into the root zone. Use about 400-600 lbs./acre and apply right before flowering. The gypsum also supplies sulfur.

Manganese: Peanuts are sensitive to manganese deficiency which are most common above a pH of 6.5. The leaves turn light yellow whole the veins remain somewhat green. Spray the plants with 5-10 lbs. of manganese sulfate per acre. Use a wetting agent.

Growth Stages: Flowering occurs about a month after emergence. The pods aren't part of the root system; as flowering fades, shoots called "pegs" develop and grow downward into the soil; the peanuts develop at the ends of the pegs. Pegging takes place about 3 weeks after flowering. The peanuts are ready for harvest when the inside of the shells begins to color and show darkened veins. The plants are fairly drought tolerant.

CASSAVA (MANIOC, YUCA)

Cassava is a drought resistant tuber crop known for its good adaption to poor soils. The tubers are ready for harvest about 9-12 months after planting (sections of the stem are used) and yield about 2-4 tons/acre (4500-9000 kgs./Ha) on poor ground but up to 16-20 tons/acre on deep, fertile soils. The tubers are very low in protein and vitamins but a good source of calories. The tubers contain varying amounts of poisonous hydrocyanic acid (HCN), and varieties can be classed as "bitter" (high HCN) or "sweet" (low HCN). Even 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 used for commercial starch production since they're better yielders. Tapioca comes from cassava. Cassava leaves contain about 25-30% protein on a dry weight basis and are commonly eaten.

Being a starch crop, cassava has a very high K requirement, and even high K soils may become deficient after several years of continuous cropping. Excessive rates of N will promote leafy growth at the expense of tubers. Average fertilizer recommendations from many countries are in the range of 40-80 lbs. N, 40-60 lbs. P_2O_5, and 80-150 lbs. K_2O per acre (or kgs./Ha.). Apply all the P and K at planting along with 1/3-1/2 of the N, followed by 1 or 2 N sidedressings later on. Split applications of K may be needed on sandy soils or under very heavy rainfall. At planting, apply the NP or NPK fertilizer in a half-circle around each seed piece about 3-4" away and 3-4" deep.

SWEETPOTATOES

Unlike potatoes, sweetpotatoes are a warm season crop. The starchy roots are ready for harvest in about 4-6 months.

Like other starchy crops, sweetpotatoes have a high K requirement. Excessive amounts of N (over 90 lb./acre or kgs./Ha.) favor leafy growth over tuber growth. Most NPK recommendations for sweetpotatoes are in the range of 50-60 lbs. N. 40-50 lbs. P_2O_5, and 80-120 lbs. K_2O per acre (or kgs./Ha.), but much lower K rates can be used on high K soils. Apply 1/3-1/2 of the N at planting along with all the P and about 1/3-1/2 of the K. Sidedress the rest of the N in 2 applications and the rest of the K in one (about 2 months or so after planting. The at-planting application should be placed in a band about 3-4" to the side and 3-4" deep.

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 starts with a yellowing and bronzing of the leaf tips and margins which gradually moves toward the center.

Soils high in organic matter tend to promote tuber diseases so manure or compost usually aren't recommended. Boron deficiency is sometimes a problem and can be cured using 5 lbs. borax per acre mixed with the NP or NPK fertilizer.

POTATOES

Potatoes prefer cool temperatures, and profitable production in the tropics is usually confined to elevations above 2000 ft. The best yields are obtained where the mean temperature during the growing season (average of daily high and low) doesn't exceed 70°F (20°C). Higher mean temperatures depress tuber growth since the plants respire much of the starch they produce instead of storing it in the tubers. Yields of up to 25-30 tons/acre are possible under top management and ideal weather, but most small farmers average around 4-6 tons/acre (9000-13500 kgs./Ha.).

Most varieties mature in about 100-130 days but full maturity is often not reached due to defoliation of the plants by fungus diseases (early and late blight). Routine applications of fungicides are essential.

Fertilizer Guidelines

Potatoes are heavy NPK feeders requiring hefty rates of fertilizer because their root system is small and they accumulate their yield in relatively short amount of time. They grow best within a pH range of 5.0-6.5 and are fairly tolerant of acidity; one effective way of controlling potato scab disease is to keep the pH below 5.5.

Nitrogen: Rates up to 120 lbs. N/acre (kgs./Ha.) or more may be profitable when improved varieties are used along with good insect, disease, and weed control. Apply about 1/3-1/2 the N at planting and sidedress the rest at hilling up time. Rates in the 60-90 lbs./Acre (kgs./Ha.) range are probably best for the average small farmer.*1

Phosphorus: Rates as high as 100-200 lbs./acre (kgs./Ha.) of P_2O_5 are usually recommended for soils low in P. P increases the number rather than the size of the potatoes, shortens maturity, and improves quality.

Potassium: Potatoes have a high K need, and even soils rich in K may become depleted after years of potato growing unless K is added. Rates for medium K soils range from about 50-100 lbs. K_2O/acre (kgs./Ha.) with up to 200 lbs./acre on low K soils under top management and growing conditions. When high rates of K are used, potassium sulfate should be substituted for potassium chloride; excess chloride lowers the quality and starch content of tubers.

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*1 Varieties vary in their N responsiveness; high N applications will favor top growth at the expense of tuber growth in some.

Methods of Application: Banding of the at-planting fertilizer is especially recommended for potatoes due to their limited root system. Place the NP or NPK fertilizer about 2" to the side of the seed pieces and slightly below them (only one band per row is needed). Apply about ½ the N, all the P, and all the K at planting; in sandy soils, it's a good idea to apply 1/2 the K at planting and the remainder at hilling up time along with the rest of the N. Place the N side-dressing about 10-12" from the row.

Magnesium deficiencies are sometimes a problem in very acid soils below pH 5.5. See p. 82 for control.

VEGETABLES

Vegies usually give excellent responses to fertilizer. They're mainly high value crops grown on a small scale intensive basis compared with field crops (corn, sorghum, rice, field beans, etc.). Most small farmers who are seriously into vegie growing tend to be better than average managers. Unlike field crops, most vegies return little if any residues to the soil. For these reasons, fertilizer rates for vegies are often considerably higher than for field crops - so is the need for applying compost and manure to help maintain an OK level of soil organic matter.

General Fertilizer Needs

The kind and amount of fertilizer needed varies a lot with the soil and vegie involved. Despite what you see in garden stores, there's really no such thing as "Tomato Fertilizer" or "Vegetable Fertilizer". Only a soil test by a reliable lab can pinpoint your situation's needs. Anyway, here's some general NPK recommendations for various vegies:

	Lbs./Acre or Kgs./Ha.		
	N	P_2O_5	K_2O
Beans	30-60	25-50	20-70
Peppers, Eggplant	80-120	40-150	40-150
Beets, Carrots, Onions	75-100	30-150	30-150
Tomatoes	100-150	70-200	50-200
Cabbage, Broccoli, Lettuce, Cauliflower	90-120	60-150	60-150
Cucumber, Squash	75-100	40-150	40-150
Watermelon	70-100	40-150	40-150

The table is pretty general. Actual rates that are best for your farmer depend on his soil's nutrient status, his management ability and capital, market prospects, yield limiting factors like poor drainage or excessive heat or rain. Don't forget to consider the nutrient value of any compost or manure you might be using when considering fertilizer needs (see pp. 59-64).

Secondary and Micronutrients: Some vegies are especially susceptible to certain secondary and micronutrient deficiencies:

Calcium: Tomato, celery.

Magnesium: Cabbage, cucumber, eggplant, pepper, tomato, watermelon.

Sulfur: Cabbage family (cabbage, turnips, radishes, cauliflower, broccoli, collards, brussels sprouts, kale, kohlrabi), onions, asparagus.

Molybdenum: Cabbage family, especially cauliflower, tomatoes.

Boron: Cabbage family, carrots, celery, tomatoes, lettuce, beets, onions.

Zinc: Beans, lima beans, corn.

Manganese: Tomatoes, beans, lettuce, onions, radish, spinach.

Copper: Common in many vegies grown on peat soils.

See pp. 81-82 for rates and pp. 155-159 for hunger signs.

APPLICATION GUIDELINES FOR VEGIES

Direct Planted Vegies

For close planted vegies like carrots, turnips, radishes, beans, mustard, and Chinese cabbage, place the fertilizer in a continuous band 2" (5 cms.) below and 2" to the side of the seed row; one band per row is enough. Apply all the P and K along with 1/3-1/2 the N; sidedress the remaining N about a month after planting. With radishes, apply all the N at planting since they mature in 3-4 weeks.

First figure out the per acre or per hectare NPK planting dosage and then calculate the amount needed per length of row (see pp.101- 7). Don't guess but work it out!

Transplanted Vegies

Tomatoes, peppers, eggplant, cabbage, broccoli, head lettuce, and onions often do better if started out in a seedbox or nursery seedbed and then transplanted to the field about 4-6 weeks later.

Seedbox or Nursery Seedbed: Even if you use a lot of compost in your seedbox soil mix, don't count on it to supply enough NPK; it's a slow release fertilizer, even more so if it's only partially rotted. Use an NPK fertilizer with a 1:2:1 or 1:3:1 ratio and aim for an application equal to about 80-100 lbs. N, 150-250 lbs. P_2O_5, and 80-100 lbs. K_2O per acre (or kgs./Ha.). That's equal to about 80 grams (3 oz.) of 12-24-12 or 10-30-10 per sq. meter (about 1½ level teaspoonfuls per sq. ft.). Mix it in thoroughly with the seedbox soil mix or broadcast it and work it into the top 4" of the nursery seedbed. N deficiency may show up after 3-4 weeks due to leaching losses. Water the seedlings with 1 tablespoon ammonium sulfate or 1½ teaspoons urea per gal. of water. Once should do it. Wash off the leaves with plain water afterwards.

Making up a Starter Fertilizer Solution for Transplants: A starter solution helps get the transplants off and running again (the transplant operation is a shock to them). Use a fertilizer with a high ratio of P like 12-24-12 or 10-30-10 if possible.

Recipe: 2-3 level tablespoons of fertilizer per gal. of water (10-15 c.c./liter). It'll take some work to dissolve it (hot water helps, so does mashing it).

Dosage: 1 cup (about 250 c.c.) per transplant hole. Pour it in before transplanting and let it drain completely before setting the plant in. *1

How to Apply Solid Fertilizer at Transplant Time: Apply the NP or NPK solid fertilizer in a half-circle 3-4" deep and 3-4" out from the plant's stem. Apply all the P and K along with 1/3-1/2 of the N. On sandy soils, it may be wise to apply half the K at transplanting and the remainder about a month later.

When to Sidedress N and How Often: Long duration vegies like tomatoes, pepper, and eggplant may need 2-4 sidedressings every 3-4 weeks after transplanting. Cabbages, broccoli, lettuce, and onions can get by well with 1-2, depending on leaching conditions. You can place the N fertilizer in a single line about 6" out from the base of the plants or make a half-circle application at the same distance. Don't worry about placing it deep (it'll leach down anyway).

*1. NOTE: The starter solution isn't meant to be a substitute for the normal application of solid fertilizer.

Just cover it enough so you can't see it (about 1/2" is great).

A Special Note on Cucumbers and Squash: They're especially fond of compost and manure (same with melons). If planting them in "hills", dig a hole a couple feet wide and a foot deep and throw about 2-3 shovelfuls of well rotted farm manure or compost in and cover with topsoil; plant the seeds in the center of the "hill".

A Special Note on "Starter" Solutions: If you use one at transplant time, you could delay the application of solid NPK fertilizer up to a week; if you do, make the half-circle about 6" out.

PASTURES

During the wet season, well managed tropical pastures can provide enough feed for normal growth of calves and beef cattle and for the production of 1-2 gals. of milk daily per cow. Supplemental feeding with high energy sources like corn, molasses, etc. will be needed for higher milk production or more rapid fattening. From 1-2 1000 lb. cattle or 1½-3 600 lb. stock can be carried per acre during the wet season (or about the same number of dairy cattle). 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). Humid region or irrigated pastures should produce 500-1000 lbs. of live weight gain per acre yearly without supplemental feeding (550-1100 kgs./Ha.).

FERTILIZER NEEDS

Tropical grasses like Elephant (Napier), Guinea, Pangola, Bermuda, Para, and Star give excellent responses to fertilizer, especially N. Soil tests will give an idea of how much is needed for a particular situation.

Nitrogen

N is the most important nutrient in terms of amount, and rates up to 300 lbs. or more per acre yearly (330 kgs./Ha.) may be profitable under good management and year around production. Aside from increasing 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.

N should be applied in several applications to cut leaching losses. 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 showed that applying 100 lbs. N/acre 6-8 weeks before the start of the dry season to recently grazed pastures will greatly increase the amount and nutritive value of the forage carried over into the dry season; with this method, grazing should be deferred(following the N application) until the dry season begins. Guinea grass produces an especially good standing hay with this method.

If urea is used, a good deal of N (up to 30-35%) may be lost as ammonia gas (see p. 73); this may be partly offset by urea's typically lower price compared to other N sources, but it's usually not recommended for pastures.

Phosphorus: P can be applied once a year since it won't leach except in super sandy soils. Rates of 50-75 lbs. P_2O_5 per acre (kgs./Ha.) are common.

Potassium: Up to 200 lbs. K_2O/acre (kgs./Ha.) are applied to low K soils under intensive management. Grasses tend to take up K in excess of their needs, so it's a good idea to split the 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 super, potassium sulfate, and ammonium phosphate sulfate (16-20-0) are good S sources. It's a good idea to apply around 20 lbs. S per acre yearly (60 lbs. sulfate or SO_4).

Calcium and Magnesium: Don't forget that ammonium or urea fertilizers have an acid effect on the soil. Chances are that liming will eventually be needed after a few years of continued N applications. Soils with a low exchange capacity (negative charge. see p.139) will drop more quickly in pH. Lime can be broadcast over the pasture. Use dolomitic limestone or else supply magnesium in another form to avoid deficiencies. Cattle are very sensitive to Mg deficiencies in pastures caused by high rates of K without supplemental Mg. In cases where both the soil and liming material are low in Mg, it may be necessary to apply 100 lbs. magnesium oxide or 400 lbs. magnesium sulfate (epsom salts) per acre yearly in 1-2 applications. Potassium magnesium sulfate has 11% Mg and 21-22% K_2O.

Micronutrients: Deficiencies are unlikely except in very leached out sandy soils or at pH's above 7.0. Molybdenum's availability decreases with increasing acidity but is unlikely to be lacking except in the case of pasture legumes (kudzu, centrosema, etc.).

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. However, animals do a lousy job at uniformly distributing the manure over the pasture; several studies have 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 by leaching too.

What about Grass-Legume Pastures in the Tropics?

What? No clover or alfalfa in the tropics? Nope, they're not adapted to the heat and humidity. Unlike temperate zone pastures, few tropical pastures contain a meaningful amount of legumes. Legumes can significantly improve the feed value of a pasture since they're higher in protein than grasses and decline less in feed value as they grow; they also can supply their own N needs as well as those of the grasses with which they're grown.

Relatively little research has been done with tropical pasture legumes, but things are improving. One problem is that many tropical legumes have trouble competing with the super rapid growth of most tropical grasses and tend to get shaded out. Others are sensitive to overgrazing or aren't very palatable. However, tropical kudzu (*Pueraria phaseoloides*, centro (*Centrosema pubescens*), siratro (*Phaseolus atropurpureus*, and several others have been grown successfully in combo 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 tropical grasses. Leucaena (*L. leucocephala*) is a perennial legume shrub tree that can be grown in rows in a pasture and used for browsing. Consult with a pasture specialist in your country concerning recommended grass-legume mixes for your area.

Fertilizing Grass-Legume Pastures: Since the legume fixes enough N for itself and for 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 with grasses, legumes are weak K extractors. Pasture legumes are susceptible to molybdenum and boron deficiencies.

USE THE PACKAGE APPROACH!

It takes much more than just fertilizer for successful beef and milk production. Good grazing management, good stock, disease control, weed control, supplemental feeding, and worming are just as vital. Some of these are touched on below:

Use Rotation Grazing

As grasses regrow after being grazed or cut, they drop in feed value (especially protein) as they mature; tropical conditions encourage rapid 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 (N helps beef up protein content). Under low management conditions, cattle are usually continuously confined at low stocking rates to one pasture; the pasture's rapid growth outstrips their ability to harvest the grass before it's become overly mature. 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 4.8% 42 days after (dry weight basis).

Rotation grazing entails dividing up the pasture into 4-6 paddocks and putting all the cattle in one paddock at a time. The size of each paddock should allow the cattle to graze down the grass in 4-7 days before moving on to the next one. About 3 weeks rest is needed between grazings to allow for 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 8" and para, elephant, and pangola down to 4-6". N fertilizer can be supplied after each grazing. Overgrazing will use up stored food reserves in the roots and weaken the stand.

Supply Silage or Hay for Dry Season Feeding

Forage quality and quantity decline disasterously during the dry season. Cattle often lose a good part of their wet season gains during the dry months and may take 4-6 years to reach slaughter weight (800-1200 lbs.). This could easily be cut 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 acre to fully utilize all the wet season's growth but too many for the scant amount of forage available during the dry season. Making hay or silage out of surplus wet season growth is the answer. Silage making is usually more feasible than hay making during wet season weather (about 2 tons of water must be evaporated from fresh cut grass to make one ton of hay). PCV's in El Salvador have helped establish a successful silage program with small cattle growers using sorghum-sudan (yields have averaged about 42 tons/acre or 95,000 kgs./Ha. in 3 cuttings taken during the 6 month wet season). They've also made good quality pangola, stargrass, and jaragua hay at the tail end of the wet season.

Control Weeds

Weeda rob spece, water, light, and nutrients from pastures, and some may be poisonous as well. Broadleaf weeds are the most common; 2,4-D herbicide givea good control of non-woody broadleafs while 2,4,5-T is better for woody species; it's not necessary to remove livestock during or after application except for dairy stock; they should stay off the pasture for a week after spraying to avoid residues in the milk.

Provide Mineral 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 (2/3 Oz.) of salt daily; older ones need about 30 grams (1 Oz.). Adding one ounce copper sulfate and 1 Oz. cobalt sulfate per 100 lbs. of iodized salt will provide a satisfactory mineral mix for grazing cattle on fertilized pastures.

Keep Animals Healthy

Follow the recommended vaccination schedule for your area (brucellosis, anthrax, blackleg and others may be needed). Periodic deworming is also essential.

Here's some suggestions on helpful cattle and pasture management references:

1. Improvement of Livestock Production in Warm Climates, Robert McDowell. W.H. Freeman Co., 600 Market St., San Francisco, CA 94104.

2. "The Intensive Management of Tropical Forages in Puerto Rico", Bul. 187, U. of P.R. Agr. Expt. Sta., Rio Piedras, P.R. Came out in 1964 but still very useful. Available in Spanish too.

3. Beef Cattle Science, M.E. Ensminger, Interstate Printers and Publishers, Inc., Danville, IL.

4. "Guidelines for Producing Chickens, Swine, and Beef Cattle in Tropical Regions", Mechell Jacob, 1979. An 80 pp. manual by a livestock consultant with lots of overseas experience. Write him c/o American Can Co., 1660 L St. N.W., Suite 201, Washington, D.C. 20036.

5. Merck Veterinary Manual, Merck & Co., Rahway, N.J. The most complete manual on livestock diseases; rather technical.

6. Animal Health Handbook, Chas. Pfizer & Co., 235 E. 42nd St., N.Y., N.Y. 10017, about $2.00.

7. The Stockman's Handbook, M.E. Ensminger, Interstate Printers & Publishers, Danville, IL. One of the best practical guides to livestock raising; though written for Stateside conditions, much of the info is relevant to the tropics.

8. An Introduction to Animal Husbandry in the Tropics, G. Williamson and W. Payne. Longmans Ltd., London.

9. Feeds and Feeding, F.B. Morrison. F.B. Morrison Pub. Co., Clinton, Iowa. The standard reference for feeds and feeding. (Out of print but available in libraries.)

10. "The Philippines Recommends for Pastures", U. of the Philippines, Los Baños. An extension bulletin on tropical pasture management; also has a good section on grass-legume pastures.

COFFEE

Of the 4 economically important species of coffee (arabica, robusta, liberica, and excelsa), the higher quality arabica coffee accounts for about 85-90% of world production and is virtually the only type grown in Latin America. Arabica produces best yields in areas with a mean annual temperature of 60-75°F and an annual rainfall of 70-80", preferably with a distinct dry season. Temperature extremes above 85°F or below 50°F will depress yields. The optimum temperatures for arabica are usually found in the 3500-5500 ft. zone of the tropics or at lower elevations in the sub-tropics. The lower quality robusta, liberica, and exclesa species need higher temperatures and are grown at lower elevations.

Coffee can be grown with or w/o shade but shading is most common. Shade trees protect against excessive sun, reduce erosion, provide lots of organic matter through leaf fall, suppress weeds, and recycle leached nutrients. Studies show that unshaded coffee often produces much higher yields but only under a favorable climate, deep soils with good tilth, and good management and fertilization.

Yields are generally much lower than they should be throughout Latin America, especially among small growers. Average yields in Costa Rica are about 500 lbs./acre but 1800-2700 lbs./acre have been obtained under a package of improved practices.

Feasibility of Fertilizers: Many coffee stands are too old and poorly managed to respond well. Even well managed coffee tends to give erratic responses and often takes 2-3 years to show results (berries are produced only on wood that is 2 years old). Secondary and micronutrient deficiencies can hamper response to NPK.

Fertilizer Needs

The berries themselves remove a relatively small amount of nutrients, but fertilizer needs are high since good vegetative growth is needed. N and P are the 2 most important for young trees (up to 3-4 years old) while N and K are the most important once good production starts.

Most coffee producing countries have conducted numerous fertilizer trials so you should be able to obtain specific recommendations.

An excellent pamphlet called "Algunas Deficiencias Minerales Comunes en el Cafeto" by L.E. Muller contains color photos of hungers signs in coffee. Write for a copy to the Instituto Interamericano de Ciencias Agricolas in Turrialba, Costa Rica.

Nitrogen: Rates range from 60-120 lbs./acre (Kgs./Ha.) of N per year. The 1st application is made when the rains begin with the rest applied later on in the wet season. Excessive N will promote leaf growth at the expense of flowering.

Phosphorus: Young trees have higher P needs than older ones in production. Rates for trees 1-5 years old range from 30-60 lbs./acre (kgs./Ha.) of P_2O_5 yearly. Trees 5-15 years old usually receive 25-60 lbs., and those over 15 years about 20-35 lbs. Applying P to the soil surface in a broad band about 2 ft. wide beginning from the outer drip line inward gives good results. Work it in slightly. Coffee has a lot of roots near the surface.

Potassium: Producing trees have much higher K needs than young ones. Rates of 20-40 lbs./acre (kgs./Ha.) of K_2O per year are common with young trees and up to 60-120 lbs. on older trees unless the soil is already high in K. K may be applied in 1-2 applications.

Calcium and Magnesium: Coffee usually grows well down to a pH of 5.0 or slightly below, although a pH of 6.0-6.5 has given best results in many cases. Higher pH's increase the chances of micronutrient deficiencies (except molybdenum). Coffee has a relatively high calcium requirement. Magnesium deficiencies are likely in very acid soils and are also caused by a high ratio of K to Mg. Soil applications of dolomitic limestone or magnesium sulfate are commonly used to cure or prevent hunger; however, it often takes 15 months or more for soil applications of Mg to work; more rapid results can be obtained by spraying the trees 3-7 times at 2 week intervals with a 1-2% solution of magnesium sulfate (epsom salts); 5-10 Oz. (140-280 grams) of epsom salts per 4 gals. water does the trick. Use a wetting agent (liquid detergent at 2-3 teaspoons per 4 gals. water.).

Micronutrients: Coffee is sensitive to micronutrient deficiencies, especially zinc, boron, iron, and manganese. Foliar sprays are the common treatment (use a sticker-spreader to promote uniform coverage and resistance to washoff). Slaked lime (calcium hydroxide) is often added to the spray to prevent foliar burn. Check with local experts. Coffee is also sensitive to manganese toxicity which occurs in very acid soils (below 5.0). Applying 5 lbs. ground limestone per tree and working it in slightly (careful with the roots!) will usually clear up the problem.

BANANAS

Bananas prefer a hot, moist climate with 60-80" rainfall fairly well distributed; though grown over a wide range of soil pH, 6.0 seems to be optimum, and yields are markedly depressed below pH 5.0. Yields range from as low as 5000 lbs./acre (kgs./Ha.) up to over 50,000 lbs./acre (kgs./Ha.)

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. A new leaf appears about every 10 days until the terminal bud (flower) emerges at 8-11 months; harvest follows in about 90 days.

Most of the plant's roots are found in the top 6" of soil though some penetrate to 2-3 ft. The roots grow out laterally as far as 15-17 ft. Lateral roots grow out from the main roots and are the only ones that absorb nutrients and water. These "feeder" roots are scarce close to the stalk, so fertilizer should be applied about 2 or more feet out from the base.

Established plantings regenerate themselves by producing several suckers per mother plant (the mother plant produces just one crop). For new plantings, either corms from older plants (one corm can yield 2 planting pieces) or those from "sword" suckers (those suckers having sword-like leaves, a thick stem, and a robust corm) are used.

Fertiliser Needs

Bananas use high amounts of N and K though their P needs are relatively low.

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 lbs./acre (kgs./Ha) applied in 3-10 applications according to leaching potential. About 80 grams (3 oz.) total N per plant is considered the minimum for commercial plantings and often 100-200 grams or more are used. All the N should be applied before flowering since it's important to stimulate early rapid growth; studies have shown a good correlation between the area of the 3rd leaf and total bunch weight. Later N applications seem to promote "openhandedness" of the bunch. Where regular fungicide spraying is done, N can be supplied foliarly with urea (5 lbs. urea per 100 gals./water for plants 1-2 months old, up to 25 lbs./100 gals. on older plants). One study showed that 65% of the urea was absorbed through the leaves in 25 minutes!

Phosphorus: P needs are relatively low compared to N and K. Most recommendations are in the 50-75 lbs./acre (kgs./Ha) range of P_2O_5. P deficiency causes a premature drying of the lower leaves. P can be applied at one application at or near planting or various times as part of an NPK fertilizer. Try about 50-100 grams (2-4 Oz.) per plant.

Potassium:[*1] K greatly increases pseudostem growth and yields, 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 a disorder called "premature yellowing" of the leaves. Soils testing below 0.2 m.e./100 grams in available K need high amounts of K. Even those testing in the 0.6-1.0 m.e. range (considered very high for most crop needs) still need some K. Most recommendations range from 100-350 lbs./acre (kgs./Ha.) of K_2O per year or about 80-250 grams per plant. It can be applied in 3 or more applications depending on leaching potential (rainfall and soil texture).

Magnesium: Deficiencies are common in acid soils, especially when high amounts of K are used. 200-250 grams (7-9 Oz.) of dolomitic limestone per plant controls deficiencies. Mg hunger causes a broad band of yellowing along the edges of the lower leaves.

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*1. The usual $N:K_2O$ ratio varies from about 1:1 to 1:2 as far as total amount applied.

<u>Iron, Zinc, and Manganese</u> deficiencies can occur at soil pH's above 6.8.

<u>Molybdenum</u> deficiency has occurred in Honduras in highly leached acid soils. Raising the pH is often effective in controlling Mo deficiency if the soil is very acid; otherwise Mo should be applied (about 1.5 lbs. of ammonium molybdate per acre).

Bananas benefit from high levels of soil organic matter. The planting hole can be partially filled with rotted manure or compost. Mulching is very advantageous.

<u>How to Apply Fertilizer to Bananas</u>: Young plants should have the fertilizer applied in a 1-2 ft. wide band around the plant about 1 foot out from the base. This can be moved out as the plants grow. Cover the fertilizer with about an inch or two of soil (careful with the roots!). Mulching will help improve uptake of P by allowing the roots to grow nearer the surface. One bulletin recommends applying 300 grams of single superphosphate (18-21% P_2O_5) mixed with the soil in the bottom of the planting hole but separated from the base of the corm by 3-4" of soil.

<u>Feasibility of Fertilizers</u>

A lot of banana growing at the small farmer level is done on a very casual and neglectful basis. Diseases, soil nematodes, insects and overcrowding are common. Don't count on fertilizer alone to boost yields profitably under these conditions.

Aside from fertilizer use, a good "package" for bananas should include: (<u>Consult local experts</u> for specific info!)

1. Proper selection and preparation of planting material. Trimming the corms and sterilizing them with hot water or clorox and water is essential to kill nematodes and diseases and prevent their spread to new ground.
2. Mulching to suppress weeds, conserve water, and add organic matter.
3. Pruning cut excess suckers.
4. A spray program for diseases and insects.
5. Cutting off the terminal bud and dipping the cut in a fungicide solution to prevent decay; this adds a couple lbs. yield to the bunch.
6. Covering maturing fruits with polyethylene clear bags that have air holes; it speeds maturity by 2 weeks and increases yields up to 20%.

PART VIII

LIMING SOILS

Soils are limed to correct excessive soil acidity (raise pH). Very acid soils (below pH 5.0-5.5 depending on the soil) adversely affect the growth of most crops because:

1. Aluminum and manganese become more soluble with increasing acidity and may become toxic to plants at pH's below 5.5. True "tropical" soils (see p. 3) tend not to release toxic amounts of aluminum until the pH approaches 5.0.
2. Very acid soils are often very low in available P and have a high capacity to tie up added P by forming insoluble iron and aluminum compounds. (See p. 41)
3. Very acid soils are likely to be low in calcium, magnesium, and available sulfur and molybdenum.
4. High soil acidity depresses the activities of many beneficial soil microbes, including those that convert unavailable organic N, P, and S to available mineral forms. Some strains of N-fixing *Rhizobia* bacteria (especially soybean, alfalfa, and some clover) have little tolerance for pH's below 6.0.

Most crops grow best within a pH range of 5.5-7.5 though micronutrient deficiencies (except molybdenum) become more likely above pH 6.8. Note that some crops like pineapple, coffee, rice, potatoes, sweetpotatoes, and watermelon tolerate more acidity than most other crops:

RECOMMENDED SOIL pH's FOR COMMON CROPS

Crop	pH Range*1	Crop	pH Range
Corn	5.5.-7.5	Potatoes*2	4.8-6.5
Sorghum	5.5-7.5	Sweetpotatoes	5.0-6.0
Rice	5.0-7.0	Peanuts	5.3-6.6
Wheat	5.5-7.5	Soybeans	6.0-7.0
Cotton	5.5-6.5	Alfalfa	6.2-7.8
Tobacco*2	5.5-7.5	Tomato	5.5-7.0
Sugarcane	6.0-8.0	Cabbage	5.5-7.5
Coffee	5.0-7.0	Lettuce	5.5-7.0
Beans	6.0-7.5	Onions	6.0-7.0
Pineapple	5.0-6.5	Peppers	5.5-7.0
Banana	5.5-7.5	Watermelon	5.0-7.0

*1. The above crops may grow fairly well one half a pH unit above and below the optimum range given.
*2. Use a pH of 5.5 or slightly below to control potato scab or tobacco black rot.

How to Tell if Liming is Needed

You can measure soil pH fairly accurately right in the field using a good quality liquid indicator kit or portable electric tester. Read the instructions carefully and measure both topsoil and subsoil pH - they're usually different; very acid soils can restrict downward root growth. Readings from the better kits like the Hellige-Truog are accurate within 0.2-0.3 pH units.

Role of the Soil's Lab: The portable kits are great for troubleshooting, but they don't tell you how much lime is needed for treating excessively acid soils. That varies a lot with the soil's negative charge (exchange capacity; see p. 37) which depends on its texture, organic matter content, and type of clay minerals. This can only be measured in a soil's lab; they'll determine pH as a routine part of soil testing and most will measure the amount of exchangeable (soluble) aluminum present (it increases as pH drops and can cause toxicities). They'll tell you if liming is needed and how much and what kind to apply.

In some cases, even a soil with a pH of 5.0 or below may still be satisfactory for most crops if its exchangeable aluminum content is low; on the other hand, the lab may recommend liming even though the pH is near 5.5. The important thing is to avoid overliming - it can be worse than not liming at all (see p. 38). Liming guides like the one on p. 140 can be used for "guestimating", but use a soil's lab whenever possible.

CALCULATING THE AMOUNT OF LIME NEEDED

Whether you use the lab's or the table's recommendation, you'll still have to make adjustment for the fineness, purity, and neutralizing value of the material you'll be using.

Types of Liming Materials and their Neutralizing Value

There are 4 basic types of liming materials:

1. Limestone (calcium carbonate, $CaCO_3$): The cheapest of all since it's taken directly from the ground and crushed without further processing. Non-caustic.

2. Dolomitic Limestone: Contains both calcium and magnesium carbonates; often recommended since purely calcium liming materials may cause magnesium deficiencies.

3. Burned lime or quicklime: Comes in the form of a white powder; very caustic. Made by heating limestone or dolomitic limestone in a kiln to drive off the CO_2 to leave calcium oxide (or calcium and magnesium oxide). The most effective per pound of the 4 materials and is more rapid acting than limestone. Tends to form granules or flakes unless thoroughly mixed with the soil.

4. Hydrated or slaked lime (calcium hydroxide): Made by burning limestone or dolomite in the presence of steam; not a popular liming material (expensive) but rapid acting; very caustic.

The neutralizing value of these 4 sources is shown below (based on 100% pure material):

Material	Neutralizing Value (compared to limestone)
Limestone	100%
Dolomitic limestone	109%
Hydrated lime	136%
Burned lime	179%

This means that 2000 lbs. of burned lime has about the same effect as 3580 lbs. of limestone of equal purity (2000 lbs. x 1.79 = 3580 lbs.).

Fineness of Liming Materials is Important!

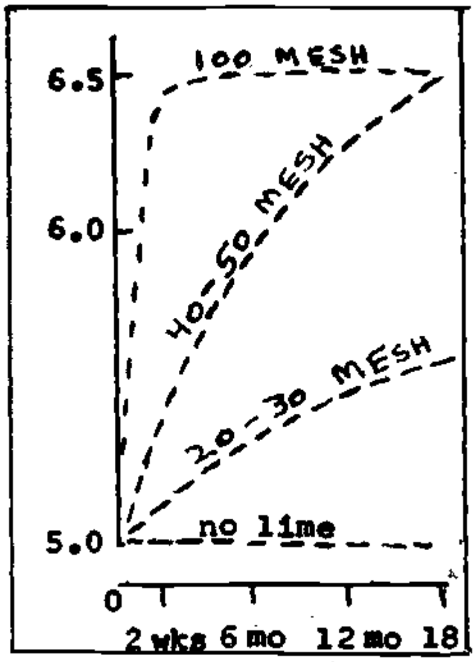
The rate that a liming material reacts with the soil depends a lot on its particle size. The finer the material, the more rapid the reaction. Even fine textured materials will take about 2-6 months to cause a significant rise in pH. Good quality burned lime and hydrated lime are naturally fine, but crushed limestone is often overly coarse.

Any type of material will contain a mix of different particle sizes. Limestone passing through a 100 mesh sieve (holes are about 1/150th of an inch on each side) will react with soil acids in just 4-6 weeks if mixed thoroughly with the topsoil. Material passing through a 40-50 mesh screen will take 12-18 months to react completely. Material in the 20-40 mesh range will have only reacted 60% in 3 years! 10-20 mesh material reacts only 30% in 3 years.*1

In the U.S., most states have lime laws requiring purity and fineness guarantees, but your country probably lacks these. The soils lab may be able to evaluate the material and do a purity and fineness analysis.

*1. A 100 mesh screen has 100 openings per inch; diameter of the openings varies with wire thickness, so there's no real standardization; a 50 mesh sceen has openings about 0.0122".

The table below shows the reaction rate of 3 mesh sizes of limestone applied at the same rate:



This graph is from a greenhouse experiment at Oregon State. Field reaction times would be somewhat slower.

Material with a satisfactory fineness should all pass through a 10 mesh screen, and at least 50% should pass through a 100 mesh screen. You'll probably have to settle for less, which means it should be applied a year or more ahead of the hoped for pH change. Or you can use more material.

Purity of Liming Materials: Unless the material has a label guarantee, it's hard to judge purity without a lab analysis. The greater the impurities, the more material will be needed.

How Soil Exchange Capacity Affects the Amount of Lime Needed

A soil's exchange capacity (negative charge) depends on its clay and humus content and type of clay minerals. The higher the exchange capacity the greater the soil's ability to resist changes in pH. That means that clayey soils often need a lot more lime than sandy soils to achieve an equal rise in pH. That's because soil's have both an active and reserve *1 acidity. The active acidity is produced by those hydrogen ions (H^+) floating around free and is what you measure when you take a soil pH reading. However, for every free floating H^+ ion, there may be thousands or more H^+ ions held by the negatively charged clay and humus particles. As the lime neutralizes the H^+ ions that are free floating, part of the huge reserve of H^+ ions held by clay and humus particles is released to take the place of the neutralized ones. The higher the amount of clay and humus, the greater the negative charge and the reserve acidity, and the more lime will be

*1. The reserve (inactive) acidity doesn't affect the pH reading.

needed to obtain a given rise in pH.

Don't get confused! In terms of soil pH (active acidity), clayey 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 (negative charge).

"Tropical vs. "Temperate" Soils

True "tropical" soils require less lime than "temperate" soils of the same texture to obtain an equal rise in pH. That's because tropical type clay minerals have a much lower negative charge than temperate types (see p. 38) and therefore less reserve acidity (buffering capacity). Remember that both tropical and temperate clay minerals occur in the tropics - that's another good reason for letting the soil lab determine the amount of lime needed instead of using a table.

"Guestimating" the Amount of Lime Needed

If you don't have access to a reliable soils lab, you can roughly estimate the amount of lime needed with this table. Check the soil periodically starting about 2 months after application to measure the effect. Lime won't react much during the dry season if the topsoil dries out.

APPROXIMATE AMTS. OF FINELY GROUND PURE LIMESTONE NEEDED*[1] TO RAISE THE pH OF A 7 INCH LAYER OF SOIL AS INDICATED:

(This table applies to true "tropical" type soils which have a lower negative charge than "temperate" soils of the same texture; that means you'll err on the safe side (too little lime) if your soil happens to have temperate type clay minerals)

	Amt. of pure limestone needed per acre or hectare to raise the pH of a soil from:	
	pH 4.5 - pH 5.5	pH 5.5 - pH 6.5
Sand or loamy sand	540 lbs./A, 600 kgs./Ha	800 lbs./A, 900 kgs./Ha
Sandy loam	1000 lbs./A, 1100 kgs./Ha	1400 lbs./A, 1550 kgs./Ha
Loam	1500 lbs./A, 1700 kgs./Ha	2000 lbs./A, 2200 kgs/Ha
Silt loam	2400 lbs./A, 2700 kgs./Ha	2800 lbs./A, 3100 kgs/Ha
Clay loam	3000 lbs./A, 3350 kgs./Ha	3800 lbs./A, 4200 kgs/Ha

You'll have to adjust these rates for the neutralizing value and purity of the material you farmer is using.

*1. Based on table in Efficient Use of Fertilizers, FAO Ag Study #43, p. 140.

PROBLEM: Suppose Paco needs to raise his soil's pH from 4.5 to 5.5 and he has a clay loam soil. The table says that about 3000 lbs./acre of pure ground limestone is needed; if he's using burned lime that's estimated to be 80% pure, how much will he need?

SOLUTION: The neutralizing value of burned lime is 179% compared to 100% for limestone so:

$$\frac{\text{Lbs. (kgs.) of limestone needed}}{\text{Neutralizing value of material}} = \text{Amt. of material needed (100\% purity)}$$

$$\frac{3000 \text{ lbs.}}{1.79} = 1675 \text{ lbs. pure burned lime needed}$$

Since the burned lime he's using is only 80% pure:

$$\frac{\text{Amt. of pure material needed}}{\text{\% purity of material used}} = \text{Amt. of actual material needed}$$

$$\frac{1675 \text{ lbs.}}{80\%} = 2100 \text{ lbs. 80\% pure burned lime needed per acre}$$

HOW AND WHEN TO LIME

Lime should be broadcast uniformly over the soil surface and then thoroughly mixed into the top 6-8" of soil by plowing or hoeing. Harrowing alone will only move the material down 2-3". When applying lime to established pastures, it can be broadcast directly over the pasture without working it in. If broadcasting lime by hand, divide the amount in half and apply one portion lengthwise and the other across; wear a mask and avoid using caustic slaked or burned lime.

Apply liming materials at least 2-6 months ahead of planting; it'll take at least this long for soil pH to be affected; this will also give caustic forms of lime time to break down to avoid possible root injury.

Where liming is expensive or its application difficult, you can try "spot" liming in the immediate row or plant zone of the crop (i.e. in cucumber or squash "hills" or a 12" diameter circle around each tomato plant). Adjust your rates accordingly. Don't mix lime and fertilizer together - it'll tie up P and release ammonia gas from N.

How Often is Liming Needed?: Maybe as often as every 2-5 years, especially if high rates of manure, compost, or other acid forming fertilizers are used (see p. 76). Sandy soils will need more frequent liming than clayey soils since they have less buffering capacity, but they'll also need lower rates.

DON'T OVERLIME!

Never raise the pH of a soil above 6.5 when liming. Don't raise the pH by more than one full unit at a time. It may only be necessary to raise the pH up to 5.5 or 6.0 for best yields of most crops.

Overliming can be worse than not liming at all because:

1. Raising the pH above 6.5 increases the likelihood of micronutrient deficiencies (except molybdenum).

2. Phosphorus availability starts declining above a pH of 6.5 due to the formation of relatively insoluble compounds with calcium and magnesium.

3. Liming stimulates the activity of soil microbes and increases losses of soil organic matter by decomposition.

PART IX

SALINITY AND ALKALINITY PROBLEMS

Salinity and alkalinity problems commonly occur in arid or semi-arid areas (rainfall under 20" a year) where rainfall or irrigation isn't sufficient to leach accumulating salts out of the root zone. The salts are released by decomposing rocks and parent material below the subsoil but are often brought in by the irrigation water which usually contains from 200 lbs. up to several tons of salt per acre-foot (12" deep layer of water on an acre).

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 the salts downward, but they'll move back up as the soil dries out between irrigations if the water volume applied is too low; 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 few feet of the surface, making it easy for salts to move upward by capillary action.

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.

1. SALINE SOILS: They contain enough soluble salts to seriously harm crop growth. The salts are mainly chlorides, sulfates, and bicarbonates of calcium and magnesium. Less than 15% of the soil's exchange capacity (C.E.C.; see p. 38) is occupied by adsorbed sodium ions, and the pH is usually below 8.5. Saline soils are also called white alkali soils since the salts tend to accumulate on the soil surface. The usual cause is lack of enough water for adequate leaching, poor drainage, or both.

2. SALINE-ALKALI (Saline-sodic) SOILS: These soils not only contain excessive amounts of soluble salts but also harmful amounts of adsorbed sodium; more than 15% of the C.E.C. is occupied by sodium ions. Though sodium is a very strong base, the pH of these soils is usually below 8.5 due to the buffering influence of the soluble salts.

3. NON-SALINE ALKALI SOILS (Sodic Soils): These soils have only low levels of soluble salts but have excessive amounts of sodium; more than 15% of the soil's C.E.C. is occupied by adsorbed sodium ions (i.e. held by clay and humus particles. The pH is above 8.5 and often as high as 10 since the buffering influence of the soluble salts is absent. The high sodium content causes these soils to have very poor physical condition; they tend to be dispersed and puddled (broken down) and may be impervious to water. Both the high pH and sodium is harmful to plants. Sodic soils are also called black alkali soils, since their surfaces are often black due to dispersed humus brought to the surface.

HOW SALINITY AND ALKALINITY HARM CROP GROWTH

1. Osmotic Effect of Salts: Soluble salts in the soil water reduce the ability of plants to absorb water through the root membranes (osmosis). If the salt concentration is high enough, water actually starts moving out of the plant roots back into the soil and the plant dies; this is called plasmolysis. At lower levels, plants suffer from leaf tip burn, stunting, and defoliation.

2. 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 bicarbonate with which sodium is often associated.

3. Boron Toxicity: Most irrigation water contains boron which becomes toxic above 1 or 2 parts per million; boron is not easily leached from the soil. High boron irrigation water may limit farming to boron tolerant crops (navy beans and nearly all fruit trees including citrus are boron sensitive).

LAB DIAGNOSIS OF SALINITY AND ALKALINITY

Soil testing labs can measure the soluble salt content of soils through electrical conductivity tests; the higher the conductivity, the higher the soluble salt content (salts are electrolytes). The readings are expressed either in millimhos or micromhos. EC or C_e = electrical conductivity. Readings can range from 0 to over 16 millimhos (16,000 micromhos), and the table on the next page gives 5 categories of salt content.

Soluble Salt Content of Soils

Electrical Conductivity (EC)		Diagnosis
Millimhos	Micromhos	
less than 2	less than 2000	No adverse affect.
2	2000	Yields of some salt sensitive crops are affected.
below 8	below 8000	Only moderately salt tolerant crops can be grown.
8-16	8000-16,000	Only salt tolerant crops.
16 up	16,000 up	No profitable cropping possible

Labs can also measure the amount of adsorbed soil sodium to determine alkali danger.

Measuring Irrigation Water Quality

The soluble salt, sodium, and boron content of irrigation water can also be tested.

Soluble Salts: The U.S. Salinity Lab at Riverside, Cal. places irrigation water in 4 categories according to soluble salt level:

Class 1: (100-250 micromhos/cm. or 0.1-0.25 millimhos/cm.)
Low salinity — Safe to use on practically all crops and soils; some leaching is needed to keep salts moving downward; problems may develop on poor drainage soils.

Class 2: (251-750 micromhos/cm. or 0.25-0.75 millimhos/cm.)
Med. salinity — Can be used to irrigate relatively permeable soils; medium salt tolerant crops are needed; leaching is essential.

Class 3: (751-2250 micromhos/cm., 0.75-2.25 millimhos/cm.)
High salinity — Only for salt tolerant crops; adequate subsurface drainage is a must as well as leaching.

Class 4: (above 2250 micromhos/cm. or 2.25 millimhos/cm.)
Very high salinity — Shouldn't be used for irrigation except under certain ideal conditions (i.e. permeable soil, good drainage, high water rates to promote good leaching).

Sodium in Water: The sodium content of irrigation water can also be measured but the potential toxicity depends on the proportion of sodium relative to the water's combined calcium and magnesium content, plus the soluble salt content. *1

*1. This ratio is called the Sodium Adsorption Ratio (S.A.R.)

RELATIVE TOLERANCE OF CROPS TO SALINITY*1

The crops are listed in order of decreasing salt tolerance within each group.

FRUIT CROPS

High	Medium	Low
Date palm	Pomegranate	Pear
Coconut	Fig	Apple
	Olive	Orange
	Grape	Grapefruit
		Peach
		Strawberry
		Lemon
		Avocado

VEGIES

Garden beets	Tomato	Radish
Kale	Broccoli	Celery
Spinach	Cabbage	Green beans
	Bell Pepper	
	Cauliflower	
	Lettuce	
	Sweetcorn	
	Potatoes	
	Carrots	
	Onions	
	Peas	
	Squash	
	Cucumber	
	Cantaloupe	

FIELD CROPS

Barley	Rye	Field beans
Sugar beets	Wheat	
Cotton	Oats	
	Rice	
	Sorghum	
	Corn	
	Flax	
	Sunflower	
	Soybeans	

*1. From "Some Principles & Practices in the Irrigation of Teeas Soils", Texas Agr. Expt. Sta, Bul. 937, p. 16

RELATIVE TOLERANCE OF SOME CROPS TO BORON

Tolerant	Semi-tolerant	Sensitive
Date Palm	Sunflower	Pecan
Palm	Acala cotton	Navy bean
Sugarbeet	Potato	Plum
Gardenbeet	Pima cotton	Pear
Alfalfe	Tomato	Apple
Onion	Sweetpea	Grape
Turnip	Radish	Kardota fig
Cabbage	Field pea	Persimmon
Lettuce	Barley	Peach
Carrot	Wheat	Orange
	Corn	Avocado
	Grain sorghum	Grapefruit
	Oat	Lemon
	Pumpkin	
	Bell pepper	
	Sweetpotato	
	Lima bean	

HOW TO RECLAIM AND MANAGE SALINE AND ALKALI SOILS

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 (like tile drains).

Either periodic leaching or continuous flooding may be used. Salt tolerant crops like beet, cotton, and barley can be grown during reclamation if flooding isn't used. The amount of water needed for leaching depends on the salt content of the soil and water and the final salt level desired. As a rough guide, about 50% of the salt in the root zone can be removed with 6" of water applied per foot of soil. About 80% can be removed with 1 ft. of water per ft. of soil.

The leaching requirement is the ratio of the salt content of the irrigation water to that of the soil. For example, where a EC of 8 can be tolerated in the root zone and irrigation water as a EC of 2 (millimhos), the leaching requirement is 2/8 or 25%; that means that 25% more water should be applied to a crop than is used up by transpiration and evaporation.

Non-Saline Alkali Soils (Sodic Soils)

Leaching alone won't remove the adsorbed (stuck on) sodium and insoluble sodium carbonate and bicarbonate. You first have to knock off the sodium ions by using a soil amendment like gypsum (calcium sulfate); limestone won't work because it's insoluble at high pH's. The gypsum reacts with the soil in 2 ways:

1. It converts insoluble sodium salts to soluble sodium sulfate which is leachable.

2. It also displaces the adsorbed sodium stuck on the clay and humus particles and replaces it with calcium; this also lowers the high soil pH.

The gypsum needs to be finely ground and should be broadcast and worked into the soil with a plow or disk; leaching can be started immediately.

On those alkali soils containing calcium carbonate, <u>sulfur</u> can be used instead of gypsum. The soil bacteria convert the sulfur into sulfate which then reacts with the lime in the soil to form gypsum. If sulfur is used, leaching should be postponed 2-3 months to allow time for the conversion. *1

Non-saline alkali soils are usually in poor physical condition for leaching due to particle dispersion. A subsoiler or deep plowing should be used to aid leaching. Leaching won't be effective if the water table is high.

Saline-Alkali Soils

Leaching by itself isn't effective since it removes only the soluble (saline) salts, leaving behind the adsorbed sodium. Free from the buffering influence of the soluble salts, the sodium can now exert its full effect in raising the pH and deteriorating soil physical condition. All you've done is convert a saline-sodic soil to a sodic soil! In a few cases, leaching without using gypsum or sulfur may be effective if the soil contains a large amount of soluble calcium or magnesium which could displace adsorbed sodium.

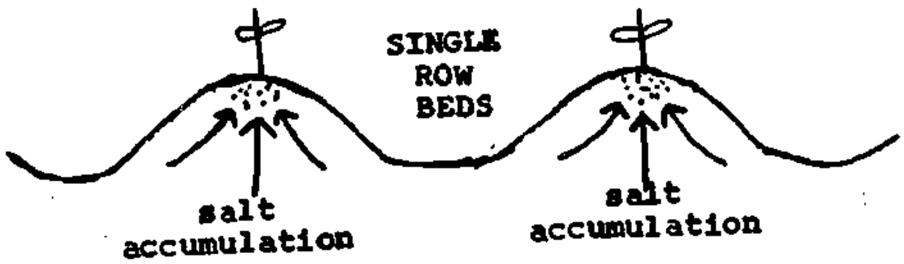
Controlling the Buildup of Salinity and Alkalinity

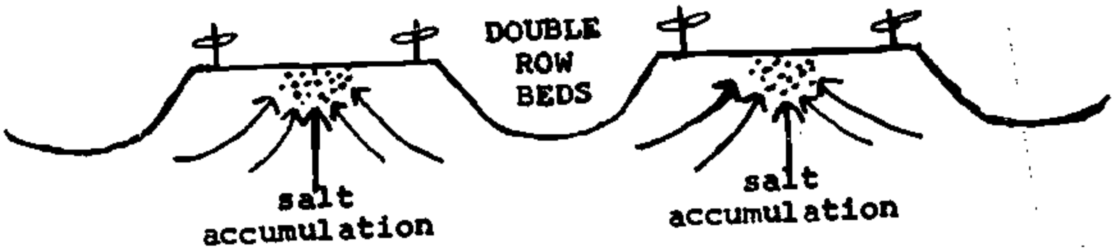
It's seldom possible to permanently rid an affected soil of salinity and alkalinity, especially if the irrigation water is the main cause of the problem. There's no economically feasible way to reduce the soluble salt content of irrigation water, but the alkali (sodium) hazard can be virtually eliminated 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.

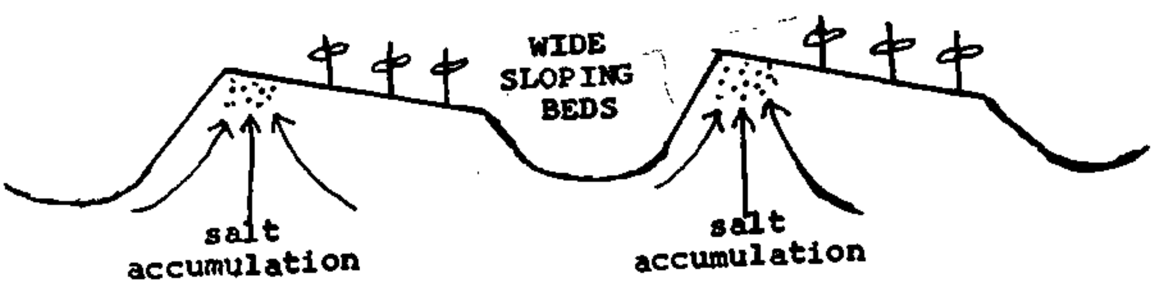
<u>Controlling Salinity</u>: Enough excess water must be applied to leach the excess salts from the root zone, yet too much water may dangerously raise the water table. Land leveling to smooth out depressions and rises will give more even distribution of water and prevent high-salt pockets from developing. Furrow irrigation will cause salts to accumulate near

*1. The soils lab will tell you how much gypsum or sulfur is needed.

the plants unless special attention is given to seedbed style. For example, if single row beds with the crop running down the center are used, upward capillary water movement will concentrate salts right where the plants are (bad news). Using double row beds with rows near the edges or sloping beds with plants on the lower 1/2 or 2/3rds of the bed cuts down salt accumulation in the immediate plant zone.







Appendix 1

SOME HANDY CONVERSIONS

1 ACRE = 4000 sq. meters = 4848 sq. yards = 43,560 sq. ft. = 0.4 hectares = 0.58 manzanas (Central America).

1 HECTARE = 10,000 sq. meters = 2.47 acres = 1.43 manzanas.

1 MANZANA (Central America) = 10,000 sq. varas = 7000 sq. meters = 8370 sq. yards = 1.73 acres.

Lbs./Acre = 0.89 x kgs./hectare = 0.58 x lbs./manzana

Kgs./Hectare = 1.12 x Lbs./acre = 0.65 x lbs./manzana

Lbs./Manzana = 1.73 x lbs./acre = 1.54 x kgs./hectare

1 LB. = 16 oz. = 0.454 kgs. = 454 grams; 1 oz. = 28.4 grams.

1 KILOGRAM = 2.2 lbs. = 1000 grams = 35.2 oz.

1 METER = 100 cms. = 1000 mm. = 39.37" = 3.28 ft.

1 CENTIMETER = 0.39" = 10 mm.

1 INCH = 2.54 cms. = 25.4 mm.

1 VARA (Central America) = 32.8" = 83.7 cms.

1 LITER = 1000 c.c. = 1000 ml. = 1.06 quarts (U.S.)

1 GALLON (U.S.) = 3.78 liters = 16 cups = 256 level tablespoons = 768 teaspoons.

1 FLUID OZ. = 30 c.c. = 2 level tablespoons

1 (level) TABLESPOON = 15 c.c. (with solids) = 18 c.c. (with liquids due to surface tension).

Appendix 2

COMPOSITION OF COMMON FERTILIZERS

NITROGEN SOURCES	N %	P_2O_5 %	K_2O %	S %
Anhydrous ammonia (NH_3)	82%	0	0	0
Ammonium nitrate	33%	0	0	0
Am. nitrate + lime	20.5%	0	0	0
Ammonium sulfate	20-21%	0	0	23-24%
Ammonium phosphate sulfate (2 types)	16% 13%	20% 39%	0 0	9-15% 7%
Mono-ammonium phosphate (2 kinds)	11% 12%	48% 61%	0 0	3-4% 0
Di-ammonium phosphate (3 kinds)	16% 18% 21%	48% 46% 53%	0 0 0	0 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	16-22%	0	8-12%
Triple superphosphate	0	42-47%	0	1-3%
Mono- & di-ammonium phosphates (see under N)				
Ammonium phosphate sulfate (see under N)				
POTASSIUM SOURCES				
Potassium chloride (muriate of potash)	0	0	62%	0
Potassium sulfate	0	0	50-53%	18%
Potassium nitrate	13%	0	44%	0
Potassium magnesium sulfate (11% Mg, 18% MgO)	0	0	21-22%	18%

NOTE: $P_2O_5 \times 0.44 = P$; $K_2O \times 0.83 = K$; $S \times 3.0 = SO_4$

DETERMINING SOIL MOISTURE BY FEEL OR APPEARANCE*1

Available Moisture in Soil	Feel or Appearance of Soil: Very coarse Texture (sand)	Coarse Texture (loamy sand, sandy loam)	Medium Texture (Fine sandy loam, silt loam)	Fine Texture (clay loam, 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.*1	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 slick 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 (100%)	On squeezing, no free water appears on soil but wet outline of ball left on hand.	Same as for sand.	Same as for sand.	Same as for sand.

*1. Based on USDA Ag. Info. Bul. No. 199.

*2. Ball is formed by squeezing a handful of soil very firmly.

Appendix 3

Appendix 4

SPACING GUIDE [1] [2]

FOR CONTOUR DITCHES OR OTHER EROSION BARRIERS

% SLOPE	DEGREES SLOPE	DISTANCE BETWEEN DITCHES Meters	Feet
5%	3°	21.6	70.8
6%		19.3	63.3
7%		17.7	58.0
8%		16.6	54.4
9%		15.8	51.8
10%	6°	15.0	49.2
11%		14.2	46.6
12%		13.4	44.0
13%		12.7	41.6
14%		12.1	39.7
15%	9°	11.5	37.7
16%		11.0	36.1
17%		10.5	34.4
18%		10.0	32.8
19%		9.5	31.2
20%	11°	9.0	29.5
21%		8.6	28.2
22%		8.2	26.9
23%		7.8	25.6
24%		7.5	24.6
25%	14°	7.2	23.6
26%		7.0	23.0
27%		6.7	22.0
28%		6.4	21.0
29%		6.2	20.3
30%	17°	6.0	19.7

(Continued)

*1. See pp.

*2. Based on data from PC/El Salvador.

% SLOPE	DEGREES SLOPE	DISTANCE BETWEEN DITCHES	
		Meters	Feet
31%		5.8	18.0
32%		5.6	18.4
33%		5.4	17.7
34%		5.2	17.0
35%	19°	5.0	16.4
36%		4.9	16.1
37%		4.8	15.7
38%		4.7	15.4
39%		4.6	15.1
40%	22°	4.5	14.8
41%		4.4	14.4
42%		4.3	14.1
43%		4.3	13.8
44%		4.1	13.4
45%	24°	4.0	13.1

Appendix B

HUNGER SIGNS IN COMMON CROPS

Before trying to spot hunger signs, read over p. 56.

Nitrogen

Corn, Sorghum, Wheat, Rice

Young plants are stunted and spindly with yellowish-green leaves. In older plants, the tips of the lower leaves first show yellowing which up the mid-rib in a "V" shaped pattern, the leaf margins staying green. In some cases, there's a general yellowing of the lower leaves. In severe N hunger, the lower leaves soon turn brown and die from the tips onward. This "firing" can also be caused by drought, which prevents N uptake.

Grain and Pasture Legumes (Peanuts, Beans, Soybeans, Kudzu, etc.)

Many legumes like peanuts, soybeans, and pasture legumes can fix all or most of their N if properly nodulated by the right strain of Rhizobia bacteria. Others like lima beans, common beans, and peas are less efficient and need fertilizer N.

N deficient legumes have pale green leaves with a yellowish tinge, starting first with the lower leaves; in later stages, leaf drop may occur.

If an efficient N fixer like peanuts or soybeans shows deficiency symptoms, check for adequate nodulation (see p.119).

Vegies

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. Flower buds turn yellow and drop off, and fruits are small.*1

Cucumbers and squash first show leaf stunting and a loss of deep green; stems are spindly and fruits are light in color (cucumbers).

Other vegies show a general leaf yellowing.

Phosphorus

Corn, Sorghum, Wheat, Rice

Hunger signs are most likely during early growth. Mild shortages usually cause stunting w/o clear leaf signs. More

*1. Tomato stems may turn purple.

Calcium

Deficiencies are rare in most crops except vegies. Blossom end-rot of tomatoes is mainly caused by calcium deficiencies. Celery will develop brown, decaying areas in its heart leaves. Carrot roots have cavity spots.

Magnesium

Corn, Sorghum, Small Grains

In corn and sorghum, a general yellowing of the lower leaves is the first sign; eventually, the area between the veins turns light yellow to almost white while the veins stay fairly green; as the deficiency progresses, the leaves turn reddish-purple along their edges and tips starting at the lower leaves and working upward. Signs aren't clear-cut in small grains.

Legumes

In early stages, soybean leaves become pale green between the main veins and then turn a deep yellow, except at the bases.

Vegies

Cabbage, cucumber, watermelon, tomato, eggplant, and pepper are the most susceptible. Tomatoes get brittle leaves which may curl upwards (can be caused by other things too); the veins stay dark green while the areas between turn yellow and then finally brown.

Where to Suspect Mg Deficiencies: Acid, sandy soils or those limed with a material lacking magnesium.

Sulfur

Where to Suspect: Volcanic soils; acid, sandy, heavily leached soils; where low sulfur fertilizers have been used.

Corn, Sorghum, Small Grains

These crops have low S needs compared to cabbage family crops and legumes. Stunted growth, delayed maturity, and a general yellowing of the leaves (as distinguished from N deficiencies) are the main signs. Sometimes, the veins may stay green which can be mistaken for iron or zinc deficiency; however, iron and zinc shortages are more likely in slightly acid to basic soils, while S hunger occurs most often in acid soils.

Legumes and Vegies

Not readily recognizable.

(Hunger signs, continued)

Zinc

Where to Suspect: Most common above a pH of 6.8.

Corn, Sorghum, Small Grains

Corn: Shows the most clear-cut zinc hunger signs of all crops. If severe, symptoms appear within 2 weeks of emergence. A broad band of bleached tissue on each side of the leaf mid-rib, beginning at the base of the leaf and occuring mainly on the lower half of the leaf is typical. The mid-rib and leaf margin stay green, and the plants are stunted. Mild shortages may causes an interveinal striping similar to iron or manganese deficiency. However, in Fe and Mn shortages, the interveinal striping runs the full length of the leaf.

Sorghum: Similar to corn but less interveinal striping, and the white band is more defined (lower part of the leaves).

Small Grains: Less common and easily spotted.

Soybeans, Beans: Area between the leaf veins becomes yellow to white; most severe on lower leaves; the affected areas may turn brown or grey and die.

Iron

Where to Suspect: Above a pH of 6.8. Sorghum is the most sensitve crop.

Corn, Sorghum: Sorghum is much more prone to iron hunger. Both crops show an interveinal yellowing that extends the full length of the leaves (especially the upper ones). Hard to diagnose in small grains. Legumes show similar interveinal yellowing.

Manganese

Where to suspect: Above pH 6.8. Sandy or heavily leached soils. Tomatoes, beans, lettuce, onion, radish,

Corn, Sorghum, Small Grains: Small grains (esp. oats) are much more sensitive than corn or sorghum. Oats show gray-brown dead spots on the leaf margins, first on the higher leaves. The spots can turn into streaks and enlongate; the upper half or 2/3rds of the leaf may fall over due to dead tissue.

Beans, Soybeans: Interveinal yellowing to whitening; veins stay green; brown spots and dead areas form (may be confused with diseases). Occurs on newer leaves.

Vegies: Tomatoes show interveinal yellowing.

Boron

Where to Suspect: Acid, sandy soils or high pH soils. Cabbage family, carrots, celery, tomatoes, and sweetpotatoes are most sensitive. Boron deficiency is the most common of all the micronutrients in vegies.

Vegies: Symptoms vary a lot with the crop. Table beets, turnips, and other root crops show dark spots on the root, usually at the thickest part. Plants are stunted with smaller than normal leaves which develop yellow and purple-red blotches; leaf stalks show a length-wise splitting. Growing point may die.

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, cabbage family (esp. cauliflower.

Legumes: Since Mo is needed by Rhizobia N fixing bacteria, Mo hungry legumes often show the same signs as in N deficiency.

Cauliflower, Cabbage, Broccoli: Inter-veinal yellowing along with cupping of the leaf margins; leaves have a whiplike appearance.

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Since 1961 when the Peace Corps was created, more than 80,000 U.S. citizens have served as Volunteers in developing countries, living and working among the people of the Third World as colleagues and co-workers. Today 6000 PCVs are involved in programs designed to help strengthen local capacity to address such fundamental concerns as food production, water supply, energy development, nutrition and health education and reforestation.

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