Soils, Crops and Fertilizer Use: A Guide for Peace Corps Volunteers

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SOILS, CROPS, & FERTILIZER USE

A Guide for Peace Corps Volunteers

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SOILS, CROPS, AND FERTILIZER USE

A GUIDE FOR PEACE CORPS VOLUNTEERS

Revised and expanded edition developed for

Peace Corps Latin America by

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FOREWORD

Successful work in ag extension takes a combination of practical and technical skills plus the ability to educate campesinos rather than merely advise them. Lack of sufficient competency in these areas on the part of the Volunteer is more often the main cause of failures in introducing improved farming practices than is campesino resistance to change. Most campesinos want to improve their crop yields and incomes, and much of their apparent conservatism is really pure shrewdness. They will adopt improved practices if these offer a reasonable assurance of a substantial return without excessive risk (provided, of course, that credit, markets, transportation, and the necessary ag supplies are available). A "middle level" practical and technical competency on your part will help keep this risk within tolerable limits and also inspire confidence among the campesinos you are working with.

The opportunities for increasing crop yields in Latin America through fertilizer use are tremendous. Returns of $2-$6 per $1 of fertilizer are common where the "package" approach of combining several improved practices is used. This manual was designed to provide you with the relevant and up-to-date information needed to get the most out of fertilizer use. Peace Corps Volunteers are in a unique position to introduce improved farming practices at the grass roots level and it's hoped that this manual will help you make the most of it.

Any suggestions for revisions or additions will be greatly appreciated.

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HANDY CONVERSION TABLE

1 ACRE = 0.58 manzanas = 0.445 hectares = 43,560 sq. ft. = 4840 sq. yards.

1 MANZANA (Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica) = 1.73 acres = 0.7 hectares = 10,000 sq. varas = 75,360 sq. ft. = 8373 sq. yards

1 HECTARE = 2.47 acres = 1.43 manzanas = 10,000 sq. meters

1 POUND = 454 grams = .454 kilograms = 16 ounces

1 KILOGRAM = 1000 grams = 2.2 lbs. = 35.2 ounces

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

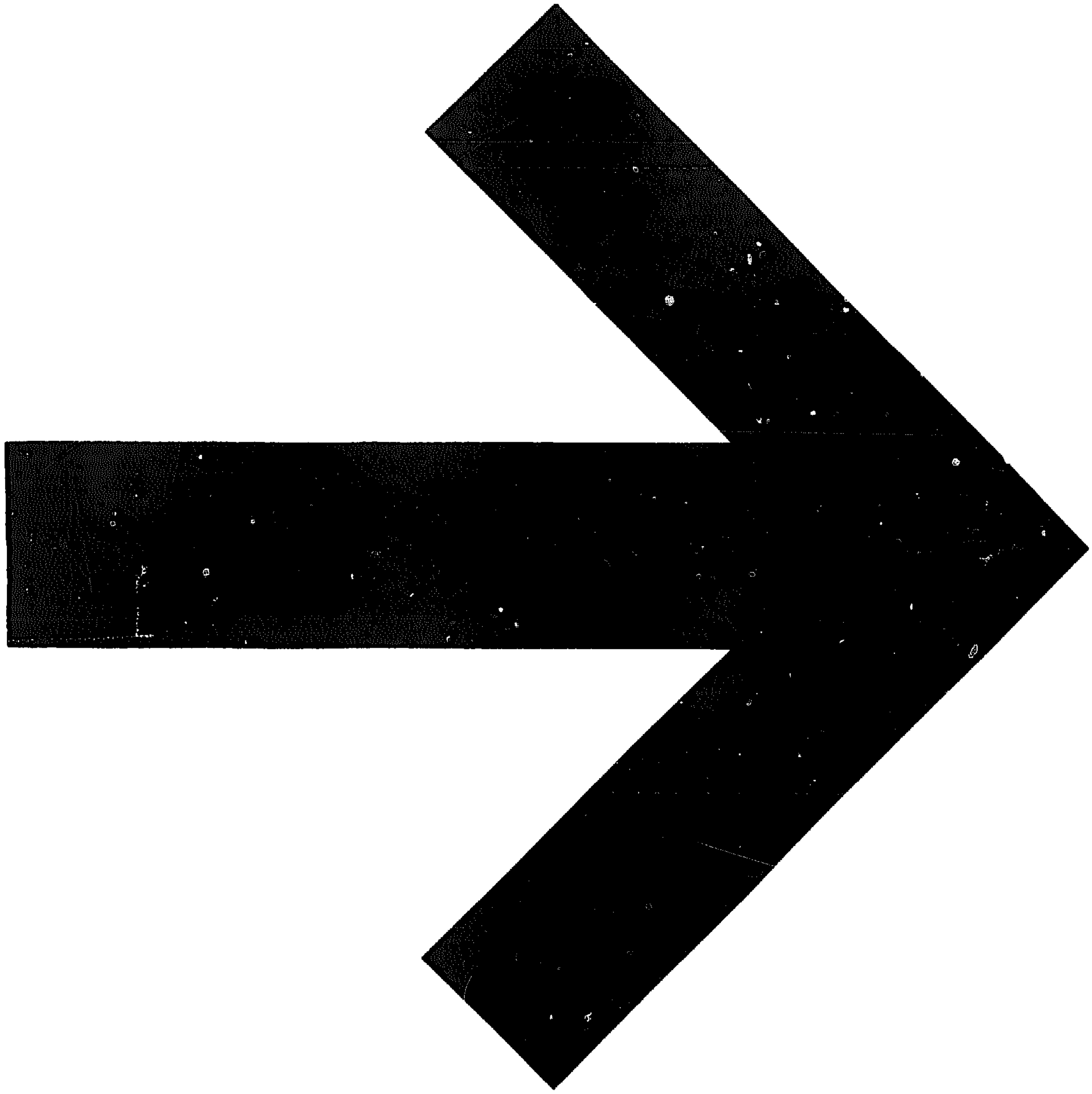


TABLE OF CONTENTS

PART I

SOME FACTS ABOUT SOILS

WHAT SOILS ARE

Most soils are slowly developed over centuries by the weathering of underlying rock material and by decaying plant matter. Some soils are developed from deposits layed down by rivers and seas (alluvial soils) or by wind (loess soils). Organic soils such as pea s and mucks are formed in marshes, bogs, and swamps.

Soils have 4 major components:
1. Mineral particles
2. Organic matter
3. Water
4. Air

A typical sample of topsoil contains about 50% pore space filled with varying proportions of air and water depending on the moisture content of the soil. The other 50% of the volume is made up of mineral particles (mainly sand, silt, and clay) and organic matter; most mineral soils contain from 2-6% organic matter in the topsoil, although variations range from a trace up to 15-20%.(soils with more than 20% organic matter are called organic soils).

Climate, parent rock, topography, vegetation, and time all influence soil formation and interact in countless patterns to produce a tremendous variety of soils.

TOPSOIL vs. SUBSOIL

Topsoil: The top 6-8" of soil is called the topsoil (the terms "surface soil" or "plow layer" can also be used). The topsoil is the major zone of root development and supplies most of the nutrients used by plants plus a large share of the water. Severely eroded soils may have little or no topsoil; however, subsoil can sometimes be converted into productive topsoil through the addition of large amounts of organic matter in the form of animal manure, crop residues, or composts.

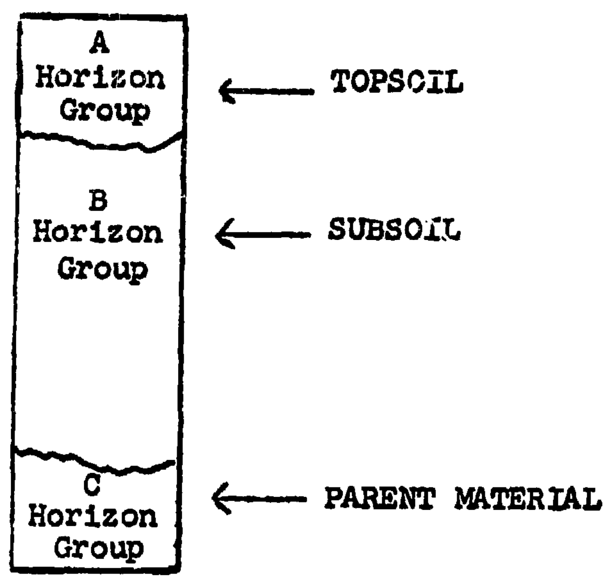
Subsoil: In contrast to the topsoil, the subsoil contains much less organic matter and plant nutrients and is more compact (less pore space). Subsoil characteristics such as drainage, permeability, and nutrient content have an important influence on crop yields.

THE SOIL PROFILE

A soil profile is a vertical section of soil extending from the surface into the parent material. Most soil profiles can be divided into a series of layers called horizons that may differ in color, thickness, texture, etc.

Every well developed soil has its own particular profile characteristics, and soils can be classified into various groupings according to profile similarities.

A typical soil profile is composed of 3 master horizons called A, B, and C which are further divided into horizons designated as A_1, A_2, A_3, B_1, B_2, etc. The A group of horizons is roughly equivalent to the topsoil, and the B group of horizons is more or less equivalent to the subsoil. The C master horizon is the parent material and is composed of partially weathered rock. A generalized profile is shown below:



The horizons and even the master horizons are not always well defined, and it may be difficult to discover the boundaries between them. In some cases, a soil may lack one of the master horizons. Remember that these layers vary markedly in thickness and other characteristics from soil to soil.

THE MINERAL PARTICLES OF SOIL: SAND, SILT, AND CLAY

The mineral particles of soil are grouped by size as follows:

<u>Sand</u>: 2-.02 millimeters in diameter
<u>Silt</u>: .02-.002 mm.
<u>Clay</u>: .002 mm. and smaller

Don't worry about memorizing the above figures, but keep in mind the general difference in size. About 10,000 average size clay particles lined up end to end would equal an inch.

Sand and Silt

Both sand and silt are just broken down rock fragments and are composed mainly of quartz (silicon dioxide or SiO_2). Silt particles are miniature sand particles. Silt, and especially sand, contribute little to soil fertility since they contain little except quartz (not needed by plants), are very resistant to decomposition, and don't have a negative charge like clay particles (see below). Some sands do contain appreciable amounts of feldspars and micas and are fairly fertile, but this is uncommon. Despite their small contribution to soil fertility, sand and the larger of the silt particles have a very beneficial effect on soil tilth (ease of working), drainage, and aeration if present in moderate amounts.

Clay

Clay particles are much smaller than sand and silt particles and are also unique in other ways:

1. Clays furnish plant nutrients: Unlike sand and silt, clays are composed of aluminum-silicate minerals which also contain varying amounts of potassium, magnesium, calcium, iron, and other important plant nutrients. Most of a soil's natural fertility comes from its clay fraction which gradually releases these nutrients in soluble form through weathering (decomposition).

2. Clay particles have a negative charge: Sand and silt particles are electrically neutral, but clays have a negative charge. The practical importance of this is that clay particles act like magnets and can attract and hold those plant nutrients that have a positive (+) charge such as ammonium (NH_4^+), potassium (K^+), calcium (Ca^{++}), magnesium (Mg^{++}) and several others. This greatly reduces the loss of these nutrients by leaching (downward movement of water through the soil).

3. Clay particles have a tremendous surface area: Each clay particle is made up of a large number of platelike units. This laminated structure combined with small particle size gives clays a tremendous surface area for the attraction of positively charged nutrients. One cubic inch of clay particles may easily have 200-500 sq. ft. of surface area which is 1000 or more times the surface area of an equal volume of coarse sand particles.

Differences among Clays

There are a number of different clays, and most soils contain two or more kinds. The clays found in most temperate zone soils differ in several important respects from those that predominate in many tropical and sub-tropical soils where weathering has been more intense.

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

In many well drained and weathered tropical and subtropical soils, the clay fraction is dominated by the <u>1:1 silicate clays</u> and the <u>hydrous oxide clays</u> of iron and aluminum. That's because centuries of weathering and leaching have removed much of the silicate thus increasing the proportion of aluminum and iron. Unlike the 2:1 clays, these "tropical" clays are considerably less sticky and plastic and have a much better physical condition. Unfortunately however, they also have a much lower natural fertility (alot of their mineral nutrients have been leached out), and also have a much smaller negative charge which means less nutrient holding ability.

Note that good drainage (favorable to leaching), ample rainfall, a fairly warm climate, and centuries of weathering are needed to form soils whose clay fractions are composed largely of "tropical" clays. Many soils in the tropics and sub-tropics are relatively young, and/or poorly drained, or have developed under low rainfall; such soils are likely to contain mainly 2:1 temperate zone clays in their clay fractions. Others contain a mixture of both kinds. A distinct red or yellow color, particularly in the subsoil, is a sign of extensive weathering and usually indicates that "tropical" clays dominate the soil's clay fraction.

<u>SOIL ORGANIC MATTER</u>

Most mineral soils contain from 2-6% organic matter in the topsoil. Despite its small proportion, organic matter plays a vital role in crop production:

1. It improves soil physical condition, especially in the case of very sandy or clayey soils.

2. It is an important storehouse of nutrients (particularly nitrogen, phosphorus, and sulfur) which again become available for plant growth as the organic matter decomposes. It's estimated that for each 1% or organic matter in the topsoil a yield of 10 bushels (560 lbs.) of corn will be obtained per acre (about 1000 LBS. PER MANZANA or 600 kilograms per hectare).

3. The minute particles of partially decomposed organic matter are known as <u>humus</u> and have a very high negative charge. Humus can account for a large share of a soil's nutrient holding capacity especially in sandy soils or those where tropical clays predominate.

4. Organic matter can increase the water holding capacity of the soil.

Maintaining and Increasing Soil Organic Matter

Although soil organic matter has very beneficial effects, it may be both impractical and uneconomical to try to significantly increase its level in large fields <u>unless</u> the level is very low to begin with. Organic matter decomposes very rapidly especially in the tropics, so tremendous amounts must be added to achieve any noticeable buildup. In an experiment in New York, the addition of 1000 <u>tons</u> of stable manure per acre of land over 40 years raised the organic matter level of the topsoil by less than 2 percentage points. Another problem is that the rate of decomposition increases as organic matter levels are built up, and the maintenance of high levels of humus is impossible from an economical and practical standpoint. However, every attempt must be made to maintain a satisfactory level of soil organic matter (usually about 3-5% in the topsoil depending on the soil and climate).

When a virgin soil is placed under cropping, organic matter levels can decline disasterously. Plowing, discing, and cultivation all speed up the loss of soil organic matter by aerating the soil and stimulating microbial activity. Most crops return small amounts of residues to the soil compared to keeping the land in forest or grass. Some suggestions for minimizing organic matter losses are given below:

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

2. Add farm manure whenever possible; composts are feasible for small areas of land like vegetable gardens (see pages 33-34).

3. Shoot for high crop yields since this means more crop residues.

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

5. Limit tillage operations (plowing, discing, etc.) to the minimum needed for adequate seedbed preparation and weed control.

6. Excessive applications of lime will greatly speed up organic matter decomposition by stimulating microbial activity. Never lime a soil above pH 6.5.

7. Rotate row crops like corn, sorghum, beans, and vegetables with pasture grasses if this is feasible. Unfortunately, few campesinos have the equipment or labor to establish and then eradicate a pasture let alone possessing enough animals to put on it.

Remember that some organic matter decomposition is necessary to release plant nutrients to the soil, but excessive losses must be avoided.

THE ROLE OF SOIL MICRO-ORGANISMS

The soil has been called a tremendous biological laboratory. A teaspoonful of soil may easily contain a billion micro-organisms. Although some types are responsible for plant diseases, most perform functions vital to successful crop production:

1. Manufacture of humus: Soil microbes convert fresh organic matter into humus (partially decomposed organic matter). It is humus that has the beneficial effect on soil physical condition and nutrient holding ability.

2. Release of plant nutrients "tied-up" in organic matter: Most of the nitrogen, phosphorus, and sulfur in fresh crop residues is in the organic form which plants can't use. In the process of decomposing organic matter, microbes convert these "tied-up" nutrients into inorganic (mineral) form which plants can use. For example, microbes change unavailable, organic nitrogen first to ammonium and then to nitrate, both of which plants can use:

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

3. Nitrogen fixation: Several types of bacteria can "fix" nitrogen from the air (they convert the nitrogen in the air into forms usuable by plants). The most important type are the Rhizobia bacteria which form nodules on the roots of legumes. They live on carbohydrates supplied by the legume host plant and in return supply the plant with nitrogen that they "fix" from the air. Most pasture legumes such as alfalfa, clovers, kudzu, and centrosema can easily satisfy their own nitrogen requirements thanks to the Rhizobia bacteria and will even supply enough for the grasses with which they are often grown in combination. Soybeans, [redacted], and pigeonpeas usually can satisfy their own nitrogen requirements so that applications of fertilizer nitrogen are unnecessary (unless the proper strain of Rhizobia bacteria is absent). Beans, peas, and lima beans are [redacted] less efficient nitrogen fixers and usually require some fertilizer nitrogen.

   Blue-green algae are considered to fix significant amounts of nitrogen in flooded rice soils.

SOME IMPORTANT SOIL CHARACTERISTICS

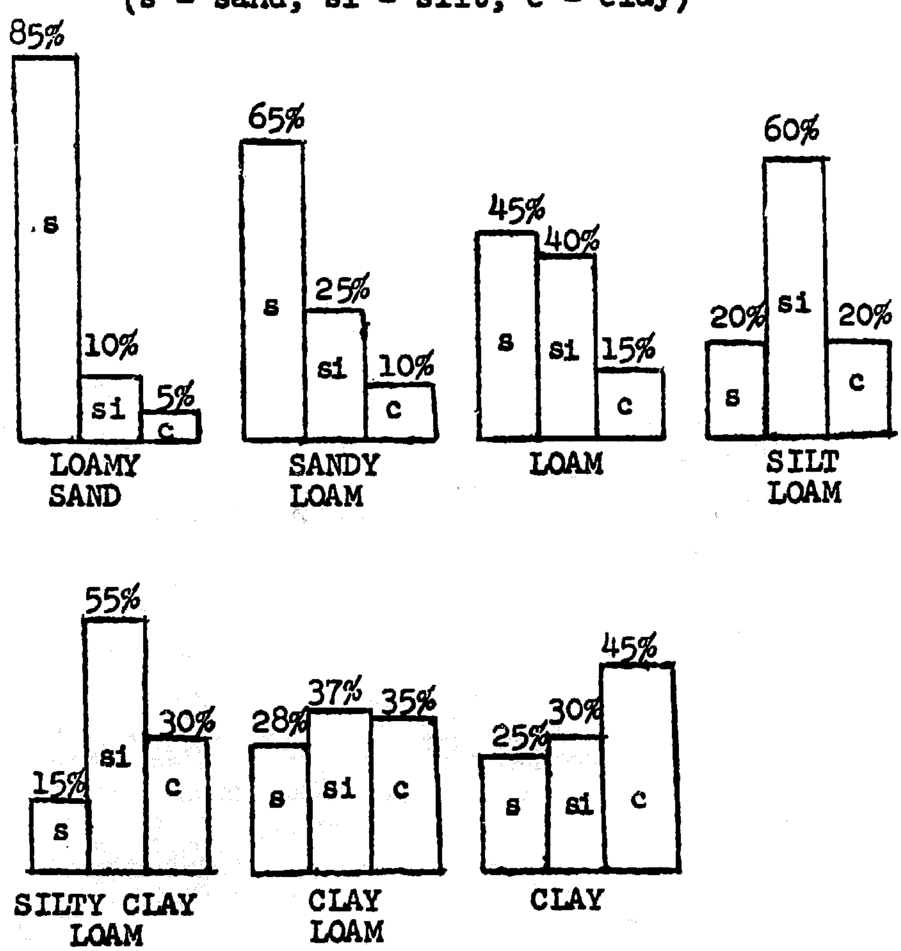
I. SOIL TEXTURE

Soil texture refers to the relative proportions of sand, silt, and clay in a soil. Texture has a big influence on a soil's potential productivity and the type of management it requires, since it affects water holding capacity, physical condition, drainage, susceptibility to erosion, and the ease with which soil fertility and organic matter can be maintained.

The 3 basic texture groups are sands, loams, and clays. These are further subdivided as follows:

SANDS (Coarse textured soils)	LOAMS (Medium textured)	CLAYS (Fine textured)
gravelly sands	sandy loams	gravelly clays
sands	gravelly loams	sandy clays
loamy sands	silt loams	silty clays
	silty clay loams	clays
	clay loams	stony clays

The relative proportions of sand, silt, and clay in various types of soil are shown below:
(s = sand, si = silt, c = clay)



How to Determine Soil Texture by the "Feel" Method

You can determine soil texture fairly accurately right in the field by feel. Pick up a pinch of soil between your thumb and forefinger; wet the sample with water or spit on it, and then rub it between your thumb and forefinger. Sand, silt, and clay each have a different feel:

Sand: Has a gritty feel.

Silt: Feels floury like talcum powder.

Clay: Feels sticky and plastic when wet; forms a ribbon or ball very easily.

Sand, silt, and clay are usually all present to some extent in most soils, so you'll get a combination of "feels". For example, if the soil is sticky feeling and plastic enough to be formed into a ribbon or ball, it's probably a silty clay or clay. If it also feels slightly gritty, you probably have a sandy clay. If a sample feels slightly gritty and talcum like with some stickiness and plasticity, it's most likely one of the types of loams in the center column above. Remember that tropical clays (see page 4) are less plastic and sticky than temperate zone clays.

You don't have to become an expert at determining soil texture, but you should become proficient enough to be able to distinguish between fine, medium, and coarse textured soils. You should also know the pros and cons of these 3 soil types and how they should be managed:

Sands (Coarse Textured Soils)

Sandy soils have very good drainage and aeration and are easily tilled. However, they are often too loose and open, tend to dry out quickly, and usually have very low natural fertility. They have little ability to hold nutrients since they are low in clay, and leaching is a serious problem. They are also usually low in organic matter. Sandy soils are very susceptible to wind erosion, but their excessive permeability makes them fairly resistant to water erosion. Additions of organic matter can improve the water and nutrient holding capacity of sandy soils.

Loams (Medium Textured Soils)

Loams usually combine the desirable qualities of both sandy and clayey soils. Sandy loams also exhibit some of the undesirable qualities of sandy soils while clay loams possess some of the undesirable qualities of clayey soils to a certain degree.

Clays (Fine Textured Soils)

Clayey soils are relatively higher in natural fertility and nutrient holding capacity than coarser textured soils. Remember, however, that the true "tropical" clays (see page 4) are definitely inferior to the 2:1 temperate zone clays in this respect.

Clayey soils have a high water holding capacity. On the other hand, they may be very difficult to work and may suffer from poor drainage and aeration; crops also tend to develop less extensive root systems in dense, clayey soils. Clayey soils need careful management, especially when it comes to tillage operations. If plowed while too wet, their structure is often broken down; if plowed when too dry, large clods may be formed which are difficult to break down. Unlike sands and most loams, clayey soils are easily compacted by machinery and animal traffic. Most clayey soils absorb water very slowly which makes them very susceptible to water erosion; this slow rate of intake may partially offset the advantage of their high water holding capacity. True "tropical" clays exhibit these undesirable physical properties to a much lesser degree than soils where temperate zone clays predominate.

II. SOIL STRUCTURE AND TILTH

SOIL STRUCTURE

Soil structure refers to the arrangement of soil particles into groups or aggregates of various shapes and sizes. The structure of a soil has a big effect on crop growth since it influences water movement (drainage), aeration, and root growth.

Soils vary in structure with depth. The "plow layer" generally has a crumb or granular structure unless the soil is very sandy or low in organic matter. The subsoil will usually have larger, more compact aggregates in the shape of blocks or columns. In some cases. a platy (plate-like) structure occurs where the aggregates are thin, horizontal overlapping plates.

What's the Best Type of Structure?

Crumb or granular structures are the most desirable, because they favor good workability, drainage, aeration, and root growth as opposed to more compact soils. Blocky and columnar structures are intermediate. A plate-like structure is the least desirable since the overlapping plates leave few continuous vertical pathways for drainage.

SOIL TILTH

Tilth describes the physical condition of a soil in relation to plant growth. 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. Tilth is influenced by soil structure, texture, amount of humus, and moisture content and is not static. For example, the tilth of a clayey soil will vary considerably with changes in moisture content.

HOW MANAGEMENT INFLUENCES STRUCTURE AND TILTH

Organic Matter

Organic matter plays a major role in the formation of good structure and tilth through its binding action. The excessively loose condition of sandy soils can be improved by the addition of large amounts of organic matter to promote aggregation. Likewise, clayey soils can be loosened up by incorporating organic matter.

The Influence of Tillage

Tillage has both good and bad effects on soil tilth. Under favorable conditions, plowing and harrowing break up clods into smaller aggregates and loosen the soil to form a more favorable seedbed. However, the long run effect of tillage may be detrimental. Stirring and shearing the soil stimulates microbial activity which accelerates the loss of organic matter so essential for maintaining desirable structure and aggregation; the mechanical action of tillage itself may also destroy desirable aggregation. The pressure exerted by repeated machinery traffic adversely affects tilth by compacting the soil. For this reason, minimum tillage systems such as plowing and planting in one operation are becoming increasingly popular in the U.S. and Europe as a means of retarding the decline in soil tilth associated with crop production. Machinery costs are also lowered.

Type of Crop

Crops such as cotton, tobacco, peanuts, potatoes and most vegetables require frequent cultivation and return small amounts of crop residues to the soil. This will have a detrimental effect on soil tilth unless certain good management practices are used. This would involve supplying additional organic matter through large applications of manure and/or using a rotation that would include a green manure crop (see page 34) or putting the land into temporary pasture.

Corn, sugar cane, grain sorghum, and rice have a less serious effect on soil structure and tilth since they return more residues to the soil (unless burning is practiced) and usually require less seedbed preparation and cultivation.

Nevertheless, careful management is still needed to prevent a serious deterioration in tilth and structure.

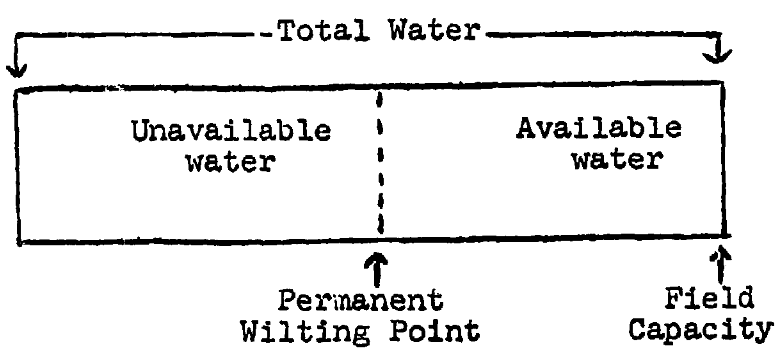
Putting land into a temporary grass or grass-legume pasture will greatly improve soil structure and tilth. However, the effects are likely to be short-lived and may last less than a year once the land is reverted back to row crops.

III. SOIL WATER HOLDING CAPACITY

How Soils Hold Water

About half of a soil's volume is pore space occupied by air and water in varying proportions. 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 the soil after a rain or irrigation. As with the sponge, a good deal of water still remains in the soil after the excess has been drained off by gravity. The soil is then 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 the soil particles. However, only about half the water held at field capacity is actually available, and plants will wilt and die long before the soil is completely dry. This is because much of the water is too strongly held by the soil particles for plants to be able to use. When the moisture level has dropped to this level, the permanent wilting point is reached, and plants will remain permanently wilted and die unless water is added.

Available water is that portion held between field capacity and the permanent wilting point as shown below:



The amount of available water a soil can hold varies quite a bit and is largely determined by texture, organic matter content, and the presence or absence of pans or layers.

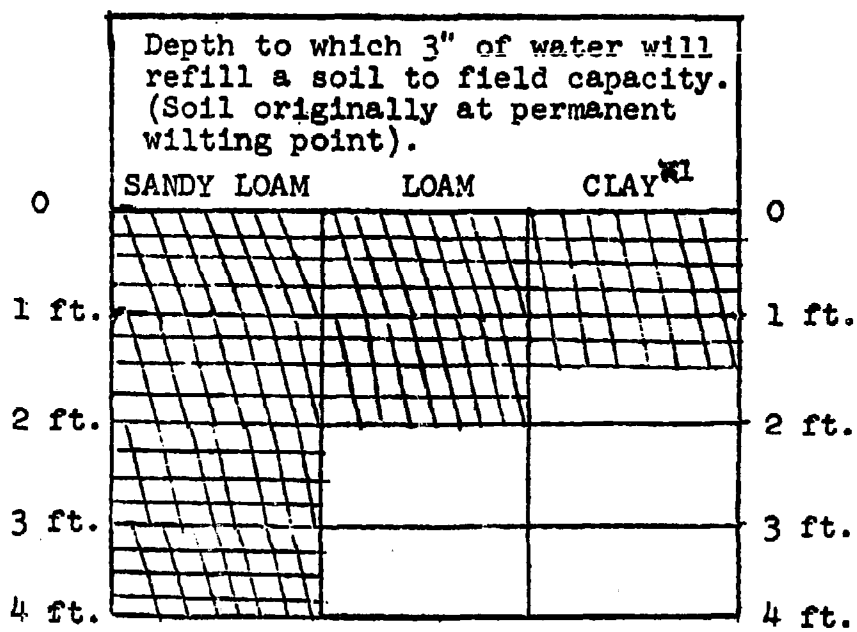
The Influence of Soil Texture and Organic Matter

As shown by the table on the next page, the amount of available water a soil can hold increases as soil texture becomes finer.

Soil Type	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"

Organic matter will increase a soil's available water holding capacity to some extent, mainly due to its favorable effect on soil structure and porosity.

When a soil receives moisture from irrigation or rainfall, the water first wets the upper layers of the soil above field capacity. The excess then moves downward, wetting the soil below to field capacity; in other words, a soil is filled from the top down not from the bottom up. The depth to which a given amount of water will refill a soil to field capacity varies with the amount of moisture the soil can hold per foot:



Although the sandy loam is wetted to field capacity to a much greater depth than the loam or clay, it holds much less available water per ft. of soil. Coarse textured soils require more frequent irrigations than finer textured soils due to their lower water holding capacity. For example, the sandy loam above can hold only 3" of available water in 4 ft. of soil, but the clay soil could hold 8" of water in 4 ft. of soil. On the other hand, there may be a tendency to under-irrigate clay soils since so much more water is needed to wet them to the same depth as coarser textured soils; this discourages deep rooting since plant roots won't grow into dry soil.

*1. Veg. Production, J. MacGillivray; McGraw-Hill Co., 1961 p. 88.

The Influence of Hardpans and other Layers

Hardpans (hardened or cemented layers) impede downward water movement and increase the amount of available water in the soil above. Unfortunately, the net result is usually not beneficial since these hardpans often create drainage problems and restrict the depth of rooting. Sandy or gravelly layers underlying finer textured soil also slow downward movement; the same is true when sandy soils are underlain by clay.

How Soils Lose Water

Soils lose water by plant transpiration, surface runoff, surface evaporation, and drainage. Drainage (gravity) only removes the surplus water held above field capacity; the rest is too tightly held to the surfaces of the soil particles to be drained off. Plant transpiration accounts for tremendous water losses; most plants transpire from 200 — 600 lbs. (25 — 75 gals.) of water into the atmosphere for every pound of dry matter produced. Little can be done to reduce transpiration losses, but it's possible to produce bigger yields with the same amount of moisture through better weed control, fertilizer use, and other good management practices. Losses of water from surface evaporation may sometimes equal transpiration losses in humid regions, and usually exceed transpiration losses in semi-arid or arid regions. In some areas, as much as 75% or more of the rainfall may be lost by evaporation. Evaporation can be reduced by placing plastic film or mulches between the rows, but this is usually too expensive except in the case of high value crops such as vegetables.

Water is also lost by surface runoff. Considerable rainfall may be lost this way on sloping soils, especially if very clayey.

IV. SOIL PERMEABILITY AND DRAINAGE

All crops except rice must obtain oxygen from the soil in order to absorb water and nutrients. A pocrly drained soils lacks enough oxygen for good plant growth. The ability of a soil to get rid of excess water is determined by its texture and structure and the existence of harpans or other layers.

How Texture and Structure Influence Drainage

Fine textured soils have many small pores through which water moves very slowly. Such soils are likely to have drainage problems in humid regions unless they have good structure. Coarse textured soils have larger pores which permit more rapid water movement.

Influence of Pans and Layers: See top of page.

Color as a Guide to Drainage

Soil color is sometimes a useful indicator of soil drainage and aeration. Colors such as red, reddish-brown, and yellow in the subsoil generally indicate good drainage. since they show that iron and manganese are in the oxidized form. In very poorly drained soils, colors such as dull greys and blues predominate in the subsoil; this is the color of iron and manganese in the reduced form (little or no oxygen). Soils subject to poor drainage during only part of the year (like during the wet season) usually have alternate streaks of bright and dull colors in the zone of fluctuating drainage; such a condition is known as mottling.

V. FACTORS AFFECTING ROOT GROWTH

Crops need extensive root systems to fully take advantage of water and nutrients. Coarse sands and gravel discourage root growth since they hold little water or nutrients. Clayey soils, especially if compacted, restrict root growth as do hardpans. Poor drainage or a high water table limit root development, since the roots of most crops (except rice) can't enter or exist in saturated soil. Excessive acidity (low pH) in the subsoil has an adverse effect on root growth. Shallow irrigations encourage shallow rooting, because roots won't grow down into dry soil.

If possible, some attempt should be made to choose crops whose rooting habits fit the particular soil you're dealing with. Cabbage, lettuce, celery, cucumbers, spinach, onions, radishes, potatoes, and rice are relatively shallow rooted and will often do better in shallow soils than deeper rooted crops like tomatoes, sweet potatoes, beans, corn, cotton, and especially alfalfa.

Soils can be classified by depth as follows:

Deep Soils: 36" or more (topsoil + subsoil)
Mod. deep soils: 20-36"
Shallow soils: 10-20"
Very shallow: less than 10"

VI. SLOPE AND EROSION

Slope is measured in terms of %. Land with a 10% slope has a drop of 10 ft. for every 100 ft. of horizontal distance. Land with a 100% slope is inclined at a 45° angle.

The slope of a field has a big effect on the amount of runoff and water erosion. Doubling the slope increases erosion losses by a factor of 2.5. An unprotected soil with a slope of only 4-5% (about a 2° angle) can easily lose 50 tons of soil per acre yearly. Length of slope is also important since long slopes allow for greater concentration of runoff water and therefore more soil loss. Doubling the length of slope increases soil losses by 50%.

Aside from the actual loss of soil, erosion seriously depletes soil fertility. The eroded material is usually 2-5 times richer in nutrients than the surface soil from which it came, because runoff water carries off relatively more of the tiny clay and humus particles (the main reservoir of fertility) than the heavier sand and silt particles.

Crops grown in rows which leave much of the soil exposed such as corn, cotton, and vegetables cause much more erosion than close seeded crops such as small grains, sugar cane, and especially pastures. Take a look at the results below of an experiment conducted in Puerto Rico on 40% slopes under 80" annual rainfall:

Treatment	Annual Soil Losses in Tons per Acre
Bare soil	126 tons
Rotation (sweetpotatoes, corn, etc.)	17.5
Sugar cane	7.5
Grass	1.2

Remember that other factors such as soil texture and the amount and intensity of rainfall also influence erosion losses.

Four methods are commonly used to combat soil erosion:

1. Contour plowing: this consists of plowing along a level line at at right angles to the slope which usually produces a curving furrow. Contour plowing is most effective on 2-8% slopes not more than 300 ft. long and will reduce soil losses by about 50%. On slopes over 8%, contour plowing becomes increasingly less effective and may reduce losses by only 20-40%.

2. Strip cropping: Strips of close sown crops such as grass or small grains are alternated with strips of row crops (corn, sorghum, beans, etc.). When the strips are prepared and planted on the contour, the system is called contour stripcropping and is most effective on 2-12% slopes less than 400 ft. long.

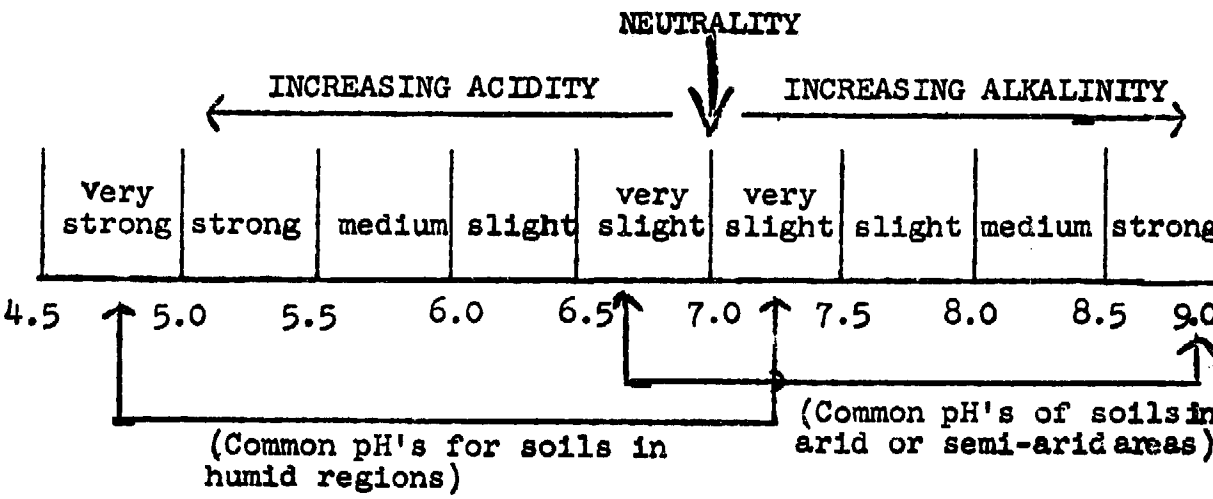
3. Terracing: Terraces are used to intercept runoff water before it builds up enough velocity to cause serious erosion. Depending on the type of terrace, the runoff water is slowed down so that it will be able to enter the soil or else is channeled in such a way that it can be slowly conducted off the field. Terraces are usually not recommended for slopes above 8-12% due to the difficulties in constructing, cultivating, and maintaining them.

4. Reversion to sod or forest: This is often the only feasible alternative on slopes above 12%.

Even slopes as low as 2-4% require some type of erosion protection. In addition to retarding erosion, the above methods will increase the amount of water available to crops by reducing runoff losses.

VII. SOIL pH

Soils can be acid, neutral, or basic (alkaline) and this is measured in pH units. The pH scale runs from 1 (maximum acidity) to 14 (maximum alkalinity), but most soils fall in the range of 5.0 to 9.0 as shown in the figure below:



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.

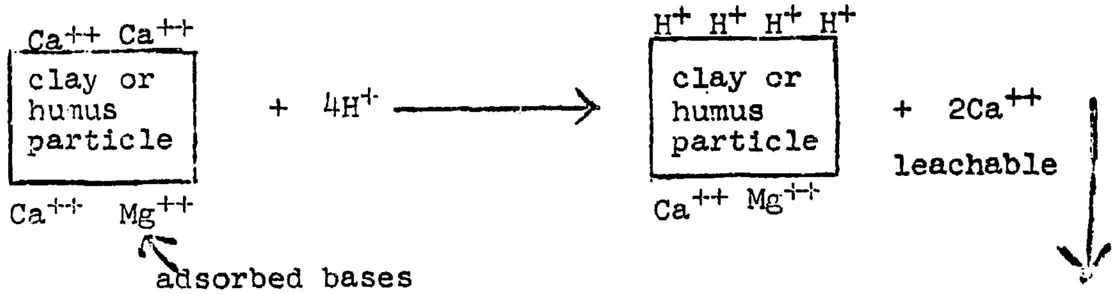
An important point is that the pH scale is logarithmic. This means that a soil with a pH of 4.0 is 10 times more acid than a soil with a pH of 5.0 and 100 times more acid than a soil with a pH of 6.0. Likewise, a pH of 8.5 is 10 times more alkaline than a pH of 7.5 but 10 times less alkaline than a pH 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 and LEACHING: As the figure above shows, soils of humid regions are likely to be acid. This is because a lot of bases such as calcium and magnesium have

been gradually leached out of these soils by rain. This is a slow process since these bases have a positive charge and are held by the negatively charged clay and humus particles; however, the acid forming H^+ ions produced by the decomposition of organic matter and acidic rocks can knock these adsorbed (stuck on) bases off the clay and humus particles back into the soil water where they can easily be leached down the soil profile by water. As H^+ ions gradually take the place of the bases on the clay and humus particles, the soil becomes more acid. A simplified example of this is shown below: (the particles are greatly enlarged!)



In contrast to soils of humid regions, those of arid or semi-arid regions are likely to be alkaline or only slightly acid. This is because less leaching of bases occurs under low rainfall since there's less water moving through the soil and also less decomposing organic matter to produce acid forming H^+ ions.

The generalization that the wetter the climate the more acid the soil doesn't always hold true. Poorly drained soils in humid regions have generally undergone relatively little leaching and may be even alkaline. Parent rock and farming practices can also modify the influences of climate.

2. PARENT ROCK: Soils formed from basic rocks such as limestone and basalt tend to be less acid than those formed from acidic rocks such as 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 pH). Manure and many chemical fertilizers will increase soil acidity; other fertilizers may slightly lessen acidity (see page 41).

Why Worry about pH Anyway?

Soil pH can greatly affect crop yields. The majority of crops will grow best within a pH range of 5.5-7.5 (moderately acid to slightly alkaline) with a pH of 6.5 being the optimum for most. Other such as sweet potatoes, potatoes, coffee, pineapple, and rice are more tolerant of acidity. The effects of excessively low or high pH's are discussed on pages 22-23.

What about Measuring Soil pH?

Soil pH is determined as a routine part of soil testing using a highly accurate pH meter called a potentiometer. However, you can make sufficiently accurate readings right in the field using a pH test kit which costs from $2-$5. The kit consists of 1 to 3 bottles of liquid indicator dyes whose color varies with the pH plus a porcelain or plastic plate with depressions into which samples of soil are placed. Just enough liquid indicator is applied to the sample so that there is a slight excess which can be separated from the soil by tilting the plate. After waiting 1-2 minutes for the indicator to react with the sample, the pH reading is made using a color chart that comes with the kit. With a little practice, these kits can provide valuable, on-the-spot information. Soil pH usually varies with depth so it's a good idea to take several readings down the profile.

pH kits can be purchased in most countries through the Ministry of Agriculture or an ag school; they can also be ordered from the U.S. The indicator dyes should be replaced about every 8-12 months for readings to remain sufficiently accurate. AVOID EXPOSING THEM TO DIRECT SUNLIGHT OR EXCESSIVE HEAT.

How Can You Change Soil pH?

Liming will lessen soil acidity (raise pH); limestone, dolomitic limestone, and burned lime are common liming materials. Gypsum (calcium sulfate) and sulfur are two common materials used to lower the pH of excessively alkaline soils.

CAUTION!: Before liming a soil, read over the section on liming (pages 95-99). Overliming a soil can cause serious problems!

GETTING TO KNOW THE SOILS IN YOUR AREA

It's impossible to make any really useful generalizations about the types of soils found in the tropics. Climate, parent rock, topography, vegetation, and time interact in countless patterns to produce a tremendous variety of soils, sometimes within a very small area. In fact, most farms contain several kinds of soil which may vary significantly in color, texture, slope, depth, drainage, tilth, and pH.

If you expect to help farmers improve their crop yields, you must get to know the soils in your area, and the best way to do this is to get out in the field and examine them. A lot of useful information can be obtained right in the field with the use of a soil probe (a shovel will do) and a pH test kit. A soil probe is a hollow metal tube about 18-36" long which enables you to quickly examine the soil profile by extracting a core of soil. Check out the characteristics that determine productivity: TEXTURE, TILTH, DRAINAGE, DEPTH, SLOPE, and pH. Learn to troubleshoot. For example, you might find that root growth is being limited by a hardpan, a high water table, or a very acid subsoil. Mottling in the subsoil indicates poor drainage during the wet season (see page 14)

Soil samples should be sent to a testing lab for specific information on nutrient status, pH, and exchange capacity (a measure of the soil's ability to hold positively charged nutrients; see page 21). Before taking samples, be sure to read pages 45-46 on how to collect samples properly.

Soil survey reports: Most Latin American countries have soil survey reports available that cover varying amounts of their territory. The surveys may be very general or detailed and consist of a soil map plus an accompanying pamphlet describing the principle soils within the area covered. Detailed surveys may show soil series. A soil series is a group of soils developed from the same kind of parent rock by a similar combination of soil forming processes and whose profiles have similar horizons and characteristics. The soils within a given series are very similar in texture, structure, depth, drainage, color, and pH; they may differ in the texture of the topsoil, however, and farming practices may have modified the topsoil in other ways.

Even very detailed maps may not be able to show exactly the way in which the different soils are interspersed since they often occur in scattered bodies of only a few acres each. The more useful surveys also give management recommendations for the different soils. Land capability maps might be available for your area; they group land into capability classes according to potential productivity and suitability for different types of crops.

If possible, try and persuade a soil scientist or competent agronomist to visit your area and spend some time looking at soils with you. They'll be able to give you valuable information about the management needs and the characteristics of the soils you're working with.

It would also be helpful to aid farmers in preparing soil maps of their own farms for use in crop planning.

PART II

UNDERSTANDING SOIL FERTILITY

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

I. AVAILABLE vs. UNAVAILABLE FORMS OF NUTRIENTS

Each of the plant nutrients occurs in both available and unavailable forms. For example, 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 only slowly becomes available through soil weathering. The rest is temporarily trapped between the plate-like units of the clay particles. Likewise, only about 1-2% of a soil's nitrogen may be available to plants. The rest is in the organic form which plants can't used until its been converted to ammonium or nitrate by soil microbes (see page 6). Only a small fraction of a soil's phosphorus is in available form. Each of the other nutrients is available in varying degrees depending on soil conditions.

II. THE NUTRIENT HOLDING ABILITY OF A SOIL

The available forms of nutrients exist as ions (atoms with a + or − charge). The positively charged ions (cations) such as K^+ (potassium), Ca^{++}(calcium), and Mg^{++}(magnesium) are attracted to the negatively charged clay and humus particles. The negatively charged ions (anions) like nitrate (NO_3^-) and sulfate ($SO_4^=$) aren't attracted to the clay and humus particles and float around in the soil water. This explains why some nutrients (− charged ones) are much more susceptible to leaching losses than others (+ charged ones). The list below divides the principle nutrients into 2 groups according to their susceptibility to leaching:

+ Charged Nutrients (Cations) (fairly resistant to leaching)	− Charged Nutrients (Anions) (easily lost by leaching)
Ammonium nitrogen (NH_4^+)	Nitrate nitrogen (NO_3^-)
Potassium (K^+)	Sulfate ($SO_4^=$)
Calcium (Ca^{++})	
Magnesium (Mg^{++})	

What about Phosphorus?: Phosphorus is an exception to the rule. Although its available forms have a negative charge, it hardly moves at all in the soil since it easily forms insoluble compounds with iron, aluminum, and calcium. This 'tie-up' is called phosphorus fixation and can be a serious problem in some soils. Don't confuse phosphorus fixation with nitrogen fixation (the conversion of atmospheric nitrogen to usable forms by Rhizobia bacteria that form nodules on the roots of legumes).

The Exchange Capacity of a Soil

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 + charged nutrients it can hold against leaching. The clay and humus content of a soil determine its exchange capacity, since these are the only 2 soil components with a negative charge. Soils with a low exchange capacity have little nutrient holding ability; they're also likely to have poor natural fertility due to their low content of humus and/or clay. Soils with the same texture can vary greatly in exchange capacity because of differences in the amount of organic matter and type of clay they contain. The table below shows the relative exchange capacities of humus and the principal types of clays.

	Exchange Capacity [*1]
Humus	150-200
Common temperate zone clays	15-100
Common "tropical" clays	2-15 (see footnote 2)

The table below will give you an idea of how much soils of similar texture can vary in exchange capacity due to differences in amount of humus and type of clay:

Soil Series Name	Exchange Capacity 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

1. For those familiar with chemistry, the exchange capacity of a soil is measured in terms of milliequivalents of cations (+ charged ions) per 100 grams of soil.

2. Remember that not all clays in the tropics can be considered "tropical". See page 4.

III. HOW SOIL pH AFFECTS CROP GROWTH

Most crops grow best within a pH range of 5.5-7.5 (see page 95 for pH tolerances of specific crops). Below or above this range, crop growth is likely to be adversely affected for several reasons:

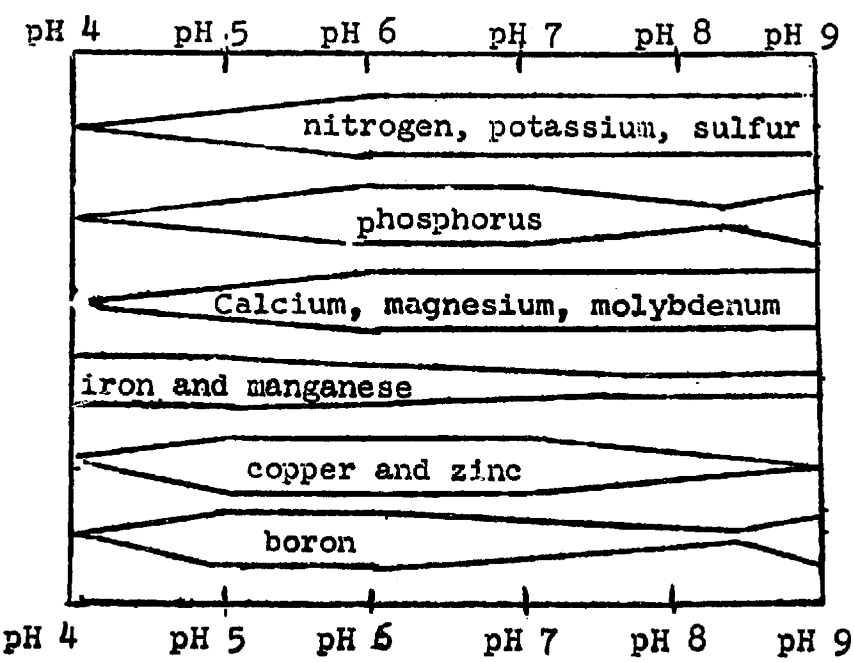
Soil pH Affects the Availability of Nutrients

1. Most beneficial soil microbes can't thrive in very acid soils, and this slows down the conversion of the nitrogen, phosphorus, and sulfur tied up in organic form to the available inorganic form.

2. Phosphorus is most available within a pH range of about 6.0-7.0. As pH falls below 6.0, increasing amounts of phosphorus become tied up in insoluble compounds with iron and aluminum. Above pH 7.0, phosphorus starts to form insoluble compounds with calcium.

3. Micronutrients: Soil pH has a big effect on the availability of the micronutrients. With the exception of molybdenum, all the micronutrients (iron, manganese, copper, zinc, and boron) become increasingly insoluble and unavailable to plants as acidity decreases and alkalinity increases. Iron and manganese are the most affected and may sometimes become deficient at pH's as low as 6.5. Molybdenum behaves in just the opposite way and becomes more available as pH is raised (acidity decreases).

The chart below gives a good visual illustration of the effect of pH on nutrient availability. The width of the bar represents the relative availability of the nutrient at various pH's.



Very Acid Soils can be Toxic to Plants

Aluminum and manganese become more soluble as acidity increases and can become toxic to plants at pH's below 5.5. Iron can cause similar problems.

Salinity and Alkali Problems

Very high soil pH's (8.0 on up) are usually a sign of salinity and/or alkali problems. Saline soils have an excessive amount of soluble salts which harm plant growth. Alkali or sodic soils contain excessive amounts of sodium attached to the clay and humus particles (the sodium ion has a + charge). Soils with both these problems are called saline-alkali or saline-sodic soils. Salinity and alkali problems are most common in arid or semi-arid areas, especially in irrigated soils.

Changing Soil pH

Liming will lessen soil acidity (raise pH). Before liming a soil, read carefully the chapter on liming (pp. 95-99). Overliming a soil can cause serious problems!

Sulfur or gypsum (calcium sulfate) are used to treat alkali soils. The calcium in the gypsum replaces the sodium attracted to the clay and humus particles; the soil is then leached with water to wash away the sodium. Sulfur can be used in place of gypsum where the soil contains enough calcium to combine with it to form gypsum. Liming materials like calcium carbonate (limestone) and burned lime can't be used to treat alkali soils since these materials become insoluble at high pH's. Non-alkali saline soils are treated by leaching alone without gypsum or sulfur since they don't contain excessive amounts of adsorbed sodium.

IV. IMPORTANT FACTS ON THE PLANT NUTRIENTS

The plant nutrients fall into two main 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)

Macronutrients vs. Micronutrients

You'll be most concerned with the macronutrients (particularly N, P, and K) since they are the most likely to be deficient. This doesn't mean that the micronutrients are any less essential. Although not nearly as common as macronutrient deficiencies, a micronutrient deficiency can have just as serious an effect on crop yields. As shown below, the micronutrients are required in much smaller amounts than the macronutrients:

Amount of Nutrients Taken Up by a
100 Bushel Yield of 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	.30
Calcium	29	Copper	.07
Magnesium	25	Boron	.07
Sulfur	17	Molybdenum	.0075

THE PRIMARY MACRONUTRIENTS

NITROGEN (N)

Nitrogen is the most universally deficient of all the nutrients. It forms an essential part of chlorophyll (needed for photosynthesis) and protein, promotes vegetative growth, and performs other important functions.

The Relative Nitrogen Needs of Different Crops

Crops that make a lot of vegetative (leafy) growth have a high nitrogen requirement. These include corn, sorghum, sugar cane, grasses, leafy and fruit vegetables, and short strawed varieties of rice resistant to lodging (tipping over). On the other hand, high rates of N tend to promote excessive vegetative growth at the expense of root or tuber growth in crops such as potatoes, sweetpotatoes, yuca (cassava, manioc), taro (malanga), and tropical yams (ñame). Pasture legumes like alfalfa, clovers, kudzu, Centrosema, and desmodiums can easily satisfy their own N requirements and those of the grasses with which they are often grown in association provided that the correct strain of Rhizobia bacteria is present. Likewise, soybeans and pigeonpeas (also legumes) can satisfy their own N needs. Beans, peas, and lima beans are less efficient nitrogen fixers and usually require medium rates of fertilizer N. Peanuts are efficient nitrogen fixers but often respond profitably to low rates of fertilizer N (20-30 lbs./acre) which carry the young plants along until the Rhizobia bacteria begin functioning efficiently.

Too Much Nitrogen may be Harmful

Too much nitrogen combined with inadequate amounts of other nutrients can adversely affect crops:

1. It may delay maturity.
2. It may cause lodging (tipping over) in tall growing varieties of rice, wheat, and other small grains.
3. It may lower disease resistance.

Available vs. Unavailable Nitrogen

Plants can only use the ammonium (NH_4^+) and nitrate (NO_3^-) forms of nitrogen. However, about 98-99% of a soil's nitrogen is stored in the organic form (unavailable) which soil microbes gradually convert to ammonium and then nitrate. Most soils are too low in organic matter to supply available nitrogen at a rapid enough rate for good crop growth, and nitrogen fertilizers are needed.

Available soil nitrogen can become tied-up when low nitrogen crop residues are turned under. That's because the microbes that decay organic matter get their energy from the carbohydrates it contains but also need nitrogen to make body protein. Most crop residues like corn and sorghum stalks, and grain straw have enough carbohydrates to stimulate tremendous microbial activity but don't contain enough nitrogen to satisfy the needs of the microbes. If the microbes can't get the nitrogen from the plowed under crop residues, they turn to the available ammonium and nitrate nitrogen in the soil to make up this deficit. If another crop is planted shortly after the crop residues of the preceding crop have been plowed under, a temporary nitrogen deficiency may result until the residues have decayed and the microbes die off and release the tied-up nitrogen. Such a nitrogen deficiency can be prevented by adding sufficient fertilizer nitrogen or by first composting the material (see page 33).

Available Nitrogen is Easily Leached

Nitrate nitrogen (NO_3^-) is much more easily leached from the soil than ammonium nitrogen (NH_4^+) since the latter is attracted to the negatively charged clay and humus particles. In the tropics and sub-tropics, temperatures are always high enough to favor a rapid conversion of ammonium to leachable nitrate. On the other hand, farmers in the Corn Belt in the U.S. can apply ammonium nitrogen fertilizers in the fall (6 months or so before planting) and not have to worry about high leaching losses. That's because soil temperatures during these months in the Northern U.S. are low enough to nearly halt the activities of the microbes that convert ammonium to leachable nitrate until conditions warm up for planting.

PHOSPHORUS (P)

Phosphorus is needed for root development, crop maturation, flowering, fruiting, cell division, stalk strength and performs other important functions.

Phosphorus Deficiencies are Widespread

1. Most soils are low in phosphorus to begin with.

2. Much of this native soil phosphorus is tied-up and unavailable to plants.

3. Much of the phosphorus added as fertilizer becomes "fixed" (tied-up) by the soil.

Highly weathered, red tropical soils are especially likely to be low in available phosphorus; such soils have high amounts of iron and aluminum which have tied up most of the native phosphorus in insoluble compounds of limited availability to plants. They also have a relatively strong ability to tie up added fertilizer phosphorus.

Soil pH Influences Phosphorus Availability

Phosphorus is most available within a pH range of about 6.0-7.0, although appreciable amounts will still be tied-up. As the pH drops below 6.0, increasing amounts of P become "fixed" by iron and aluminum; above pH 7.0, P fixation by calcium and magnesium increases.

Fixation of Added Fertilizer Phosphorus

Only about 5-25% of the fertilizer phosphorus you apply to an annual crop (e.g. corn, beans, sorghum, rice, most vegetables, etc.) will be available during its growth. The rest becomes "fixed" (tied-up) in the form of fairly insoluble compounds with iron and aluminum or with calcium and magnesium. Fortunately, this "fixed" P is not permanently lost to plants since a good deal of it slowly becomes available to future crops. That's why applying phosphorus fertilizer is like putting money in the bank and making small, gradual withdrawals. (NOTE: Don't confuse P fixation with N fixation! They're completely different concepts).

Phosphorus Doesn't Leach: Except in very sandy soils, losses of P by leaching are negligible.

Getting the Most out of Phosphorus Fertilizers: The response you get from phosphorus fertilizer depends alot on how and when it's applied. Be sure to read pages 54-55 before applying phosphorus.

POTASSIUM (K)

Aside from influencing the general vigor of plants, potassium plays an important role in starch and sugar formation, root growth, disease resistance, and stalk strength. Starch and sugar crops such as sugar cane, bananas, cassava (yuca), potatoes, sweet potatoes, yautía, and taro have very high potassium requirements.

Soils of volcanic origin are likely to have rather high potassium contents. Many Central American soils fall into this category and often will not give economic responses to potassium fertilizer except after a number of years of intensive cropping (especially with starch and sugar crops).

Available vs. Unavailable Potassium: There's a big difference between the amount of total potassium in the soil and the amount actually available to plants. About 90-98% of a soil's total K is in the form of rock particles that weather very slowly. A good portion of the remaining 2-10% is temporarily trapped between the plates of clay particles, while only 1-2% of the total may be available to plants. Temperate zone clays have a much higher capacity to tie-up added or native potassium than true "tropical" clays (see page 4). Potassium fixation is generally a much LESS serious problem than phosphorus fixation.

Plants Differ in Ability to Extract K: Grasses and cereal crops (corn, rice, etc.) often show less response to added potassium than legumes (alfalfa, clovers, kudzu, beans, peas, etc.). Grasses and cereals appear to be more efficient potassium extractors and can utilize some of the native soil K that is unavailable to legumes. Lack of potassium is one of the main reasons that legumes often fade out of grass-legume pastures.

Losses of K from the Soil: Available potassium occurs as the K^+ ion which is attracted to clay and humus particles. Leaching losses are not serious except on coarse textured soils where K will be better utilized if applied in 2-3 applications.

"Luxury Consumption": If enough K is available, plants may continue taking it up in excess of their needs. However, recent work has shown that this "luxury consumption" is only a problem when the levels of other nutrients are inadequate. Most agronomists still feel that luxury consumption is a definite problem with pasture grasses.

Potassium Induced Magnesium Deficiencies: See under Magnesium.

THE SECONDARY MACRONUTRIENTS (Ca, Mg, and S)

CALCIUM

Calcium is not only an important plant nutrient but also plays and important role as a liming material to lessen soil acidity (raise pH). While large amounts of calcium are needed to raise soil pH, much smaller quantities are required in plant nutrition. Even very acid soils may contain enough calcium as far as plant needs are concerned, but soil pH may be too low for optimum growth. The available form of calcium has a + charge and is fairly resistant to leaching.

MAGNESIUM

Magnesium deficiencies are most likely to occur in coarse textured, acid soils (usually below pH 5.5). Magnesium is often used as a liming material with calcium in the form of dolomitic limestone (a mixture of calcium and magnesium carbonates). Like calcium, magnesium is fairly resistant to leaching.

The Calcium:Magnesium Ratio: If the ratio of Ca to Mg in the soil becomes too high, some crops will develop magnesium deficiencies even though the soil appears to have enough magnesium. This is usually more of a problem on coarse textured 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 unless a magnesium containing fertilizer such as potassium magnesium sulfate is to be used. Tobacco is particularly sensitive to calcium induced magnesium deficiencies.

Potassium Induced Magnesium Deficiencies: Large amounts of available potassium in the soil depress the uptake of Mg by plants. This may cause or intensify magnesium deficiencies not only in crops but in animals grazing forages grown on such soils. This malady in livestock is known as hypomagnesemia, also called grass tetany or staggers. These deficiencies can be corrected by applying dolomitic limestone or a magnesium containing fertilizer to the soil.

SULFUR

Sulfur is important in protein synthesis, is required by Rhizobia bacteria for nitrogen fixation, and forms part of several vitamins; it is also related to oil formation. Crops of the crucifer family (cabbage, turnip, raddish, cauliflower, mustard, kohlrabi, collard, kale, and broccoli) plus onions and asparagus have very high sulfur requirements and generally take up from 20-40 lbs. of actual sulfur per acre. Tobacco, cotton, and legumes (beans, peas, peanuts, alfalfa, clovers, kudzu, etc.) have relatively high sulfur requirements and take up from 15-20 lbs. of S per acre. Small grains, grasses, and corn have lower sulfur requirements and are less likely to suffer deficiencies.

Where to Suspect Sulfur Deficiencies: Sulfur deficiencies aren't nearly as common as those of N, P, and K but are most likely to occur in coarse textured soils under high rainfall where leaching has been intense. Many soils of volcanic origin tend to be low in sulfur. Farmland near industrial areas usually receives sufficient sulfur from the atmosphere produced by the burning of coal and other sulfur containing fuels. Continued use of fertilizers containing low amounts of sulfur will eventually cause a sulfur deficiency in many soils.

Leaching Losses of Sulfur: Available sulfur occurs as the $SO_4^{=}$ ion and large amounts can be lost by leaching especially in sandy soils under high rainfall. A good part of the soil's sulfur is tied-up in undecomposed organic matter which microbes convert to available sulfate. Organic sulfur is an important reserve since it doesn't leach in this form.

Recent work has shown that appreciable amounts of sulfur can be retained against leaching in the subsoil if high in "tropical" clays (see page 4). This sulfur is available to plants once their roots can reach it.

THE MICRONUTRIENTS

The micronutrients perform many vital functions but are required in very small amounts (see table on page 24). The difference between toxic and deficient levels is often very small. For example, as little as one ounce of molybdenum per acre might alleviate a deficiency for several years, while an application of only 3-4 lbs. might severely injure plants.

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

Prevalence of Micronutrient Deficiencies: Micronutrient deficiencies are much less common than those of macronutrients but can be serious when they occur.

Where to Suspect Deficiencies:

1. Highly leached (acid), coarse textured soils.

2. Muck or peat soils.

3. Soil pH's above 7.0. All the micronutrients except molybdenum decrease in availability as pH increases above 7.0 or so. (see page 22)

4. Intensively cropped soils fertilized with macronutrients only.

Vegetables, legumes, and tree crops (coffee, cacao, fruits, and nuts) are generally more susceptible to micronutrient deficiencies than grasses and cereals; sorghum, however, is very sensitive to iron deficiencies.

Micronutrient Toxicities: Remember that iron and manganese may become toxic to plants in very acid soils (usually below pH 5.5) due to their excessive solubility. Poor aeration and drainage increases these toxicities.

Correcting Deficiencies or Toxicities

1. Adjusting pH: Molybdenum deficiencies can often be more satisfactorily corrected by raising the soil pH if the soil is very acid. Raising the soil pH is usually the best way to correct iron and manganese toxicities and about the only way of correcting aluminum toxicities.

2. Soil applications of micronutrients: This is of varying effectiveness since some micronutrients (particularly iron and manganese) are very readily "fixed" when applied to the soil in their common fertilizer forms, especially at soil pH's of 7.0 and above. Special forms of these nutrients called chelates are much less subject to fixation.

3. Foliar applications: Since such small quantities are needed to correct a deficiency, spraying the plants is a very practical method and also avoids soil fixation problems. In some cases, common fungicides such as Maneb (contains manganese), Zineb (zinc), and Cupravit (copper) are used to supply micronutrients to vegetable and orchard crops in conjunction with controlling fungus diseases.

PART III

ORGANIC FERTILIZERS

Organic fertilizers are of plant or animal origin and include animal manure, composts, and green manure crops.

The Value of Organic Fertilizers

1. Low Nutrient Content: Manure, compost, etc. have a much lower nutrient content than CHEMICAL fertilizers. For example, 1 ton of average farm manure supplies only as much nitrogen as 30 lbs. of ammonium nitrate, as much phosphorus as 10 lbs. of single superphosphate, and as much potassium as 20 lbs. of potassium sulfate (in terms of readily available nutrients). However, so long as large amounts are applied, organic fertilizers can be valuable fertilizers.

2. Provide Needed Organic Matter: Although relatively low in plant nutrients, organic fertilizers have very beneficial effects on soil physical condition by improving tilth, permeability, and water holding capacity. However, large amounts must be applied to obtain these benefits, and it's doubtful that most campesinos would have enough available to cover any more than a small amount of land adequately. A further problem, especially in the tropics, is that organic matter decomposes very rapidly meaning that the benefits of organic fertilizers may be rather short lived. Nevertheless, such additions of organic matter are essential where low residue crops such as cotton, corn silage, or vegetables are grown.

I. ANIMAL MANURE

Amount Produced

Animals produce a surprising amount of manure as shown by the interesting table below:

Tons of Manure Produced Annually Per 1000 Lbs. Live Weight

Animal	Solid	Urine	Total	Bedding	Bedding + Excrement
Horse	7.2 tons	1.8 tons	9 tons	3.0 tons	12 tons
Cow	9.5	4.0	13.5	1.5	15
Pig	9.1	6.1	15.2	3.0	18.2
Sheep	4.1	2.1	6.2	3.5	9.7
Hen	4.2	0	4.2	---	---

Fertilizer Value of Farm Manure

The fertilizer value of farm manure depends alot on the type of animal, its diet, kind and amount of bedding used, and how the manure is stored and applied. Poultry and sheep manures usually have a higher nutrient value than horse, pig, or cow manure. On the average, farm manures contain about 10 lbs. of N, 5 lbs. P_2O_5, 10 lbs. K_2O, and 10 lbs. sulfur per ton plus small amounts of other nutrients (this takes into account normal storage and handling losses which amount to 25-50%). This is equivalent to a .5-.25-.5 fertilizer formula (see pages 35-36 for an explanation of fertilizer formulas plus P_2O_5 and K_2O). However, only about 50% of the nitrogen, 20% of the phosphorus, and 50% of the potassium is readily available to plants during the first growing season. The rest gradually becomes available to future crops which means that farm manure has good residual fertilizer value.

Farm Manure is very Low in Phosphorus: Farm manure has far too little available phosphorus in relation to its content of available nitrogen and potassium. If you used farm manure as the only source of fertilizer, you'd stand a good chance of running into a phosphorus deficiency. Such problems can be avoided by fortifying farm manure with 50-60 lbs. of single superphosphate or equivalent per ton. This not only beefs up the phosphorus content but also reduces the loss of nitrogen as ammonia gas from the manure. Work has also shown that the fixation of added fertilizer phosphorus can be reduced by mixing it with manure. Usually, it will be a lot easier to apply phosphorus to the soil instead of trying to mix it with the manure, however.

Storing and Applying Manure

Farm manure is best applied a few weeks to a few days before planting time. If applied too far in advance, you'll lose a lot of nitrogen by leaching and as ammonia gas. Manure must be plowed or disced under shortly after being spread on the field to reduce ammonia losses. A delay of one day in incorporating manure into the soil may cause a 25% loss of nitrogen and a 50% loss in 2 days. A modest, even application over a large acreage usually gives higher returns per ton of manure than a very heavy application on a smaller acreage. Rates of 8-12 tons per acre are best for most crops except with poultry and sheep manure where 4-5 tons should be the limit. Row crops like corn, sorghum, potatoes, and vegetables will usually give better responses to manure than pastures and small grains. Best results are obtained on poorer land.

Manure should be stored in piles with steep sides to shed water and good depth to reduce leaching losses by rain. Compacting manure helps reduce losses from excessive heating and assures better fermentation. Very strawy manure low in nitrogen may cause a temporary nitrogen deficiency when added to the soil unless well rotted (see page 25). This can be avoided by either adding nitrogen to the manure (3 lbs. of N per ton of manure) or to the soil itself. You'll usually be applying additional nitrogen and other nutrients anyway, because manure alone can seldom supply enough readily available nutrients for good yields unless very high amounts are applied.

II. COMPOSTS

You can make compost by letting vegetable matter decompose to humus. Although relatively low in nutrients, compost can greatly improve soil fertility, as well as physical condition if applied in sufficient amounts.

For several reasons, composting may not be advantageous or practical compared with directly adding fresh material to the soil:

1. Composting requires a lot more work.

2. Many studies have shown that the turning under of fresh crop residues to which nitrogen has been added gives significantly higher yields than applying composts made from a similar amount of the same material (plus the same amount of nitrogen).

3. Much more organic matter is added to the soil when fresh residues are turned under rather than composted. About 50% of the organic matter is lost during composting.

On the other hand, there may not be suffieient time or water available to adequately decompose turned under crop residues before planting time which might cause a temporary nitrogen "tie-up" (see page 25) unless sufficient fertilizer nitrogen is added. It's also not always possible to add fresh organic matter to the soil when it becomes available if there's a crop growing. Composts are most useful and feasible for small vegetable gardens where enough can be applied to have a worthwhile effect.

How to Make Compost

Leaves, crop residues, weeds, sawdust, coconut husks, manure, garbage, etc. can be composted. The compost pile should be located in a well drained area protected from rainfall. Start with a 12" layer of organic material and pack it down. Then sprinkle some nitrogen fertilizer over the layer (about 1-2 lbs. of N per 100 lbs. of dry weight). This is especially necessary when materials low in nitrogen like sawdust, woodchips, corn stalks, or straw are being used. Phosphorus and potassium fertilizer can also be added to beef up the nutrient content. Some recommend alternating the 12" layers with 1-2" layers of soil; this isn't absolutely essential but may help to conserve more of the nitrogen. The pile should not be built up any higher or wider than 5-6 ft; this assures that the microbes in all parts of the pile will get enough air. A moisture content of 50-70% by weight is ideal for rapid decomposition, and the pile may have to be watered every week or so if protected from the rain. Don't let water run out the bottom of the pile since it will leach out nutrients. The pile should be turned every 2-3 weeks and packed down again to encourage rapid and uniform decomposition. More frequent turning will speed things up.

Coarse materials like corn stalks cause excessive aeration and loss of heat and moisture. They should be cut up into 6" pieces or can be mixed with finer material. On the other hand, fine materials like sawdust exclude too much air and should be mixed with other materials or else the pile will have to be turned more frequently.

Too much or too little moisture will slow down decomposition. Turning the pile will reduce excessive moisture. Fresh, green material is often too high in moisture for composting and should first be wilted or mixed with drier material.

The pile is self-insulating and should heat up well. The high temperatures will kill disease organisms, weed seeds, and insects except in the outer parts and bottom of the pile.

When Is it Ready?: Composting is completed when the material inside the pile crumbles easily in the hand. Small piles usually take about 1-3 months under favorable moisture and temperature conditions.

III. GREEN MANURE CROPS

In many parts of the world, crops such as alfalfa, kudzu, cowpeas, clovers, and rye are plowed under in the green, immature stage. The turning under of such a green manure crop not only adds organic matter to the soil, but may also add considerable nitrogen *if* a legume is used.

It's doubtful that green manuring is a worthwhile practice, particularly for campesinos. Unlike farm manure, green manures usually don't increase the amount of soil humus, because they decompose rapidly due to their immature state. Furthermore, adding such readily decomposable material often stimulates more rapid decomposition of the organic matter already present in the soil. Green manure crops may also seriously deplete soil moisture in drier areas and lower the yield of the succeeding crop. The nitrogen added by leguminous green manures is very variable and can often be more economically supplied by chemical nitrogen fertilizers. Finally, most land is needed for the production of food crops, and campesinos are not likely to want to take land out of production for green manuring.

PART IV

CHEMICAL FERTILIZERS

Chemical (inorganic) fertilizers have a much higher nutrient content per pound than organic fertilizers but have no direct beneficial effects on soil physical condition; however, they do indirectly improve physical condition by raising crop yields enabling a greater amount of crop residues to be returned to the soil.

Chemical fertilizers are usually white or grey and are mainly in the form of granules or powders. Some come in liquid form, but it's doubtful that you'll be using these.

Fertilizers fall into two general classes:

1. Straight or simple fertilizers: These contain only one of the primary nutrients (N, P, or K). Ammonium sulfate, superphosphate, and potassium chloride are examples.

2. Mixed or complex fertilizers: These contain 2 or all 3 of the primary nutrients. Examples are potassium nitrate, di-ammonium phosphate, 12-24-12, 16-20-0, etc. If a fertilizer contains all 3 primary nutrients, it is often called a complete fertilizer which is misleading. Complex fertilizers may be manufactured by mechanical or by chemical mixing. The latter are preferred since each particle or granule has the same nutrient composition and there is no problem with segregation.

UNDERSTANDING THE FERTILIZER LABEL

All fertilizers manufactured by reputable companies have a label on the sack or a tag that gives the nutrient content. The label not only lists the content of primary nutrients but also the amount of sulfur, magnesium, and micronutrients if these are present in significant amounts (the calcium content isn't given since this nutrient is much more cheaply supplied as lime or gypsum.

The 3-Number System: Fertilizer identification is facilitated by the use of a 3-number system that indicates the content of primary nutrients. The 3 numbers represent the percentages of N, P_2O_5, and K_2O in that order. For example, a 12-24-12 fertilizer contains 12% N, 24% P_2O_5, and 12% K_2O (12 lbs. N, 24 lbs. P_2O_5, and 12 lbs. K_2O per 100 pound sack). A 0-45-0 fertilizer contains no nitrogen or potassium but 45% P_2O_5.

The Fertilizer Ratio: The ratio of the 3 primary nutrients to eachother is called the fertilizer ratio. A 12-24-12 fertilizer has a 1:2:1 nutrient ratio as does a 6-12-6 or 10-20-10 fertilizer. 15-15-15 and 10-10-10 fertilizers both have a 1:1:1 ratio.

A typical fertilizer label might look something like this: (both English and Spanish are given in this case, but most labels are in only one language)

Net Wt. 100 lbs.
(Peso Neto: 100 lbs.)

10 — 20 — 10

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

N, P_2O_5 K_2O vs. N, P, K

Note that the nitrogen content is expressed in terms of elemental nitrogen (N) but that phosphorus and potassium contents are expressed in terms of P_2O_5 (called phosphoric acid or phosphorus oxide) and K_2O (called potash). This N-P_2O_5-K_2O system has been used for the past century and unfortunately causes much more confusion than expressing nutrient content on a straight N-P-K basis.

The U.S. is in the process of switching over from the old N-P_2O_5-K_2O system to the more simple N-P-K system. This doesn't change the nutrient content of the fertilizer but only changes the way of expressing the nutrient content. Most fertilizers sold in Latin America use the old system, but same may use a double label that expresses the nutrient content by both systems. Most fertilizer recommendations in Latin America are given in terms of N, P_2O_5, and K_2O, but you should know how to convert from one system to the other. The conversion factors are shown below:

$$P \times 2.3 = P_2O_5 \qquad P_2O_5 \times .44 = P$$

$$K \times 1.2 = K_2O \qquad K_2O \times .83 = K$$

The 2 sample problems below should clear up any confusion:

PROBLEM #1: On an N-P_2O_5-K_2O basis, a fertilizer has a formula of 16-24-8. What would the formula be if the N-P-K system were used?

SOLUTION: Since P = P_2O_5 X .44 and K = K_2O X .83, you'd multiply 24 (P_2O_5) by .44 and 8 (K_2O) by .83 to get an N-P-K formula of 16-10.5-6.5.

PROBLEM #2: Suppose you receive back soil test results that recommend applying 35 lbs. of actual P per acre, but the phosphorus content of your fertilizer is expressed in terms of P_2O_5. How many lbs. of P_2O_5 would be needed to supply 35 lbs. of P?

SOLUTION: Since P_2O_5 = P X 2.3, you'd multiply 35 lbs. by 2.3 and find out that about 80 lbs. of P_2O_5 will supply 35 lbs. of P.

Forms of Nutrients in Fertilizers

You may be wondering why you can't have a 100 lb. sack of fertilizer that contains 100 lbs. of N, P_2O_5, and K_2O. For example, ammonium nitrate contains just 33.5% nitrogen. What about the other 66.5%? The formula for ammonium nitrate is NH_4NO_3 which shows you that the rest of the weight is made up by hydrogen (H) and oxygen (O). It would be impossible to have a sack containing 100% nitrogen, since pure nitrogen (N) is a gas, and plants can't use it in this form anyway. Let's take another example: single superphosphate contains about 18% P_2O_5 or 8% P. Since the chemical formula for single superphosphate is $Ca(H_2PO_4)_2 \cdot CaSO_4$, you can see that the rest of the weight is made up of calcium, hydrogen, oxygem, and sulfur.

CHARACTERISTICS OF COMMON CHEMICAL FERTILIZERS

I. NITROGEN FERTILIZERS

Nearly all nitrogen fertilizers carry nitrogen in the ammonium (NH_4^+) or nitrate (NO_3^-) form. In terms of leaching, there's really little difference between the 2 forms since ammonium is fairly rapidly converted to nitrate by soil microbes in warm climates (see page 25).

Ammonium Nitrate (33.5% N): A good source of N but is hygroscopic (absorbs humidity) and shouldn't be left in open sacks. If applied to the surface of alkaline soils (above pH 7.0) without being covered, some of the ammonium will be lost as ammonia gas. Can become explosive if mixed with oil but is safe otherwise. Has an acid effect on soils.

Ammonium Nitrate with Lime (20.5% N): Same as ammonium nitrate but is coated with dolomitic limestone to neutralize it's acidity and doesn't absorb humidity as much.

Ammonium Sulfate (20.5% N): Also contains about 23% sulfur (about 69% SO_4). Has good handling and storage properties. Has an acid effect on the soil. Considerable nitrogen may be lost as ammonia gas if applied to the surface of alkaline soils without covering it.

Urea (45-46% N) Has the formula $CO(NH_2)_2$ and its nitrogen is in the amide form. When added to the soil, it's rapidly converted to ammonium and then to nitrate by microbes. Regardless of soil pH, some nitrogen will be lost as ammonia gas if urea is applied to the surface without covering it; this is especially true on pastures where losses can be as high as 30%. Urea is the most concentrated solid source of nitrogen available. If placed too near the seed or seedling, urea may have a burning effect due to the release of ammonia. May sometimes contain excessive amounts of biuret which is very toxic to plants, but this is rare except under conditions of improper manufacture. Urea has an acid effect on the soil. Absorbs humidity in storage. Can be fed to ruminant animals (cattle, sheep, goats) as a protein source; the bacteria in the rumen (first stomach) can manufacture protein from the nitrogen which then becomes available to the animal; however, urea is very toxic to animals at anything but very low levels, and can only be fed under certain conditions.

Sodium Nitrate (16% N): Also called Chilean nitrate (nitrato chileno). Tends to be relatively expensive per pound of N due to its low nitrogen content. Can easily "burn" seeds or seedlings due to its high salt content (see page 61). Has a basic effect on soils (see page 41). Absorbs humidity readily which causes handling problems.

Potassium Nitrate (13% N): See under potassium fertilizers.

Ammonium Phosphate Fertilizers: These include mono-ammonium phosphate (11-48-0 or 12-61-0), di-ammonium phosphate (16-48-0, 18-46-0, or 21-53-0), and ammonium phosphate sulfate (16-20-0 or 13-39-0). They have an acid effect on the soil. See also under phosphorus fertilizers.

Anhydrous Ammonia (82% N): The most concentrated source of fertilizer nitrogen available. Is stored under pressure as a liquid but reverts to a gas when exposed to the air; is applied to the soil with a special applicator. It's doubtful that you'll ever use this fertilizer. Anhydrous ammonia is acid forming.

Mixed Fertilizers: There are numerous mixed fertilizers that contain nitrogen. 14-14-14, 15-15-15, 12-24-12, 20-20-0, 10-20-10, etc. are common types.

II. PHOSPHORUS FERTILIZERS

Single Superphosphate (16-22% P_2O_5, 8-12% S): A very common phosphorus fertilizer and also a good source of sulfur. Nearly alb the phosphorus in "single super" is water soluble, but most of it becomes "fixed" (tied-up) by the soil (see page 26). Has no effect on soil pH.

Triple or Concentrated Superphosphate (42-46% P_2O_5): A more concentrated source of P than single super but has a much lower sulfur content (about 1-3% S). Its phosphorus is also nearly all water soluble as with single super and is just as subject to soil tie-up.

Ammonium Phosphate Fertilizers

1. Mono-ammonium phosphate (11-48-0 or 12-61-0): Tends to give better results than di-ammonium phosphate on alkaline soils (above pH 7.0). A good source of P.

2. Di-ammonium phosphate (16-48-0, 18-46-0, 21-53-0): Also a good source of P. May injure the seed by ammonia burn if placed too close, especially on alkaline soils. Mono-ammonium phosphate is less likely to cause seed injury, but DAP is perfectly safe if applied correctly (see page 61).

3. Ammonium phosphate sulfate (16-20-0, 13-39-0): both are good sources of N, P, and also S. 16-20-0 contains from 9-15% S and 13-39-0 contains about 7% S.

All the ammonium phosphate fertilizers have an acid effect on the soil (see page 41).

Mixed Fertilizers: Numerous kinds.

Heat Treated Rock Phosphates: These vary in P content. Made by heat treating natural phosphate rock to make its phosphorus more soluble. However, none of the P is water soluble, although most becomes slowly soluble under acid conditions. May be a cheap source of P in countries with phosphate deposits but is only recommended for acid soils and should be finely ground. It only slowly becomed available as the acids dissolve it but is just as subject to soil tie-up as other forms of P. Due to its gradual availability, it has a good residual effect and is useful for building up a soil's phosphorus content since it's so relatively cheap. It should not be used as the sole source of P for annual crops (cereals, most vegetables, etc.) since it won't become available fast enough.

III. POTASSIUM FERTILIZERS

Potassium chloride (muriate of potash), potassium sulfate, and potassium nitrate as well as other mixed fertilizers are common sources of potassium. There is little difference between these sources, although potassium chloride isn't recommended for tobacco which is sensitive to chloride. Potatoes and sweet potatoes are also sensitive to high amounts of chlorides. (See table on page 43 for K content of common potassium fertilizers).

IV. SECONDARY NUTRIENT FERTILIZERS (Ca, Mg, S)

Calcium and Magnesium

Ca and Mg are most commonly supplied as limestone ($CaCO_3$) and dolomitic limestone (a combination of calcium and magnesium carbonates). Remember that Ca and Mg play important roles as liming materials to lessen acidity as well as being plant nutrients. It takes much more Ca and/or Mg to raise soil pH than to satisfy the nutrient needs of most plants . Gypsum (calcium sulfate) has no effect on soil pH and is used to supply calcium to plants with high requirements for this nutrients but which prefer an acid soil (like peanuts).

Magnesium sulfate (9-11% Mg) and potassium magnesium sulfate (11% Mg) are other sources of magnesium aside from dolomitic limestone. The Mg content of fertilizers is often expressed in terms of MgO (magnesium oxide). The conversion is Mg X 1.66 = MgO, MgO X .6 = Mg.

Sulfur

A number of common fertilizers are good sources of sulfur such as single superphosphate (12% S), ammonium sulfate (23% S), 16-20-0 (9-15% S), and potassium sulfate (17% S). Aside from 16-20-0, a number of other mixed fertilizers contain varying amounts of sulfur. Sulfur deficiencies are on the increase due to the growing use of high analysis fertilizers (high in primary nutrients) which have little or no sulfur. It's a good idea to include a sulfur bearing fertilizer in you fertilizer program, especially on acid, sandy soils.

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

V. MICRONUTRIENT FERTILIZERS

Some mixed fertilizers may contain small amounts of micronutrients (check the label), but levels are usually too low to correct deficiencies. Separate micronutrient fertilizers such as ferrous sulfate, manganese sulfate, zinc sulfate, borax (sodium borate), etc. can be purchased. Iron, copper, zinc, and manganese also come in chelated form which greatly reduces soil tie-up of these nutrients (common in near neutral and acid soils; see page 29). Some fungicides containing micronutrients such as Maneb (contains Mn), Zineb (zinc), and Cupravit (copper) are used to supply micronutrients to orchard and vegetable crops as well as to control fungus diseases at the same time.

SOME FERTILIZERS AFFECT SOIL pH

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

1. All ammonium nitrogen fertilizers (except ammonium nitrate with lime) are acid forming; that's because the conversion of ammonium (NH_4^+) to nitrate (NO_3^-) releases H^+ ions (acid formers). Urea, ammonium sulfate, ammonium nitrate, and most mixed fertilizers containing ammonium N are acid forming.

2. Nitrate nitrogen fertilizers in which the nitrate is combined with a strong base have a slightly basic effect: calcium nitrate, potassium nitrate, sodium nitrate.

3. The straight potassium or phosphorus fertilizers have no effect on soil pH: potassium chloride, potassium sulfate, and the superphosphates.

4. Large applications of manure will lower soil pH (increase acidity).

You don't have to worry about neutral or basic fertilizers, but continued use of acid forming fertilizers over several or more years may lower soil pH enough to require liming. The rate that pH drops with the use of acid forming fertilizers depends on the amount and kind applied and particularly on the texture of the soil, generally speaking, the coarser the texture, the more rapid the drop in pH. This doesn't mean that you should avoid using acid forming fertilizers, because they are the most economical and available; in fact, they even have a beneficial effect on excessively basic soils. Don't try to neutralize the acidity of acid forming fertilizers by adding lime to them or you'll lose a lot of nitrogen as ammonia gas. Many fertilizer labels will state the amount of limestone needed to neutralize the acidity per 100 lbs. or per ton of fertilizer. However, this doesn't mean that you must apply lime to the soil each time you use an acid forming fertilizer. That's both unnecessary and time consuming since it usually takes at least several years of large fertilizer applications to lower the pH enough to require liming (unless the soil is fairly acid to begin with).

The table on the next page shows the relative acidity of the common acid forming fertilizers in terms of the amount of limestone needed to neutralize the acidity produced per 100 lbs. of material and per lb. of nitrogen.

Relative Acidity of Acid Forming Fertilizers*1

Fertilizer	% Nitrogen	Lbs. of pure limestone needed to counteract the acidity produced per: 100 lbs. fertilizer	per lb. of N
Ammonium nitrate	33.5%	60 lbs.	1.8 lbs.
Ammonium sulfate	20.5%	110 lbs.	5.3 lbs.
Ammonium phosphate-sulfate (16-20-0)	16%	88 lbs.	5.3 lbs.
Urea	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.

If you were to apply 100 lbs. of actual nitrogen per acre annually for 5 years in the form of mono-ammonium phosphate and ammonium sulfate, the effect on soil acidity would be roughly equivalent to a loss of about 2600 lbs. of pure limestone according to the above table (5.3 X 100 X 5). Depending on the soil's texture and initial pH, liming may or may not be needed. Check the liming table on page 98 and suppose that the soil is a clay loam. The effect of "losing" 2600 lbs. of limestone would probably increase acidity in the topsoil by less than 1 pH unit (however, this might be serious if the pH were low to begin with). On the other hand, if the soil were very coarse textured, the effect might be much more serious since such soils are much less resistant to pH changes (SEE P. 97)

Many agronomists feel that the official figures on relative acidity shown above are too conservative. Further work has shown that the figures shown for urea and ammonium nitrate might well be doubled and those for the others increased by 30%. At any rate both sets of figures are only very rough guides.

COMPOSITION OF COMMON FERTILIZERS

NITROGEN SOURCES	N %	P_2O_5 %	K_2O %	S%
Anhydrous ammonia (NH_3)	82%	0	0	0
Ammonium nitrate	33.5%	0	0	0
Am. nitrate with lime	20.5%	0	0	0
Ammonium sulfate	20-21%	0	0	23-24%
Ammonium phosphate sulfate (2 kinds)	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 (Chilean nitrate)	16%	0	0	0
Potassium nitrate	13%	0	44%	0
Urea	45-46%	0	0	0
PHOSPHORUS SOURCES				
Single superphosphate	0	16-22%	0	8-12%
Triple superphosphate (Concentrated superphos.)	0	42-47%	0	1-3%
Mono- & di-ammonium phosphates	(see under nitrogen sources)			
Ammonium phosphate sulfate	(see under nitrogen sources)			
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	0	0	21-22%	18%

NOTE: To convert P_2O_5 to P, multiply by 0.44. To convert K_2O to K, multiply by 0.83. To convert S to SO_4 (sulfate), multiply by 3.0.

PART V

HOW TO DETERMINE FERTILIZER NEEDS

Unfortunately, it's not yet possible to determine fertilizer needs with complete accuracy. However, 4 basic methods can be used to get a fairly good idea of a crop's nutrient needs on a particular soil:

1. Soil testing
2. Plant tissue testing
3. Fertilizer trials
4. Spotting visual "hunger signs"

Of these, soil testing is most commonly used method but should be supplemented by one or more of the others for best results.

I. SOIL TESTING

The availability of a number of nutrients can be measured with varying accuracy by soil testing, and fertilizer recommendations can then be made based on the test results, type of crop and soil, climate, etc. Soil testing labs also measure the pH and usually the exchange capacity (see page 21) of the sample on a routine basis. If requested, many labs can check the salinity and alkali hazard of the soil and irrigation water (see page 23).

For several reasons, soil testing is only approximately accurate:

1. Few labs run tests for micronutrients on a routine basis; furthermore, satisfactory soil tests haven't yet been developed for most of the micronutrients and also sulfur. Tests for available nitrogen (nitrate and ammonium) are not very accurate since the amount of available N fluctuates considerably with temperature and moisture changes which affect microbial activity (see page 25).

2. Improper soil sampling is one of the biggest causes of inaccuracy. Each sample sent to the lab is supposed to be a composite of a number of sub-samples taken over a fairly uniform area of soil (i.e. similar in texture, color, drainage, and previous fertilizer treatments). However, samples from dissimilar areas are often lumped together. Even a seemingly uniform soil can vary surprisingly in nutrient content from spot to spot. Another problem is that soil samples are usually only requested from the topsoil, although the nutrient content of the subsoil can also be very important.

3. For soil tests to be reasonably accurate, THEY must be correlated with actual crop responses to fertilizer. These correlations vary with the type of soil and crop which means that numerous field and pot trials are needed. Many Latin American countries lack sufficient correlation work, but the situation is rapidly improving.

4. Even if soil tests were 100% accurate and you followed the recommendations, the crop might still suffer from a nutrient deficiency due to excessively cold, hot, wet, or dry weather, all of which slow nutrient uptake.

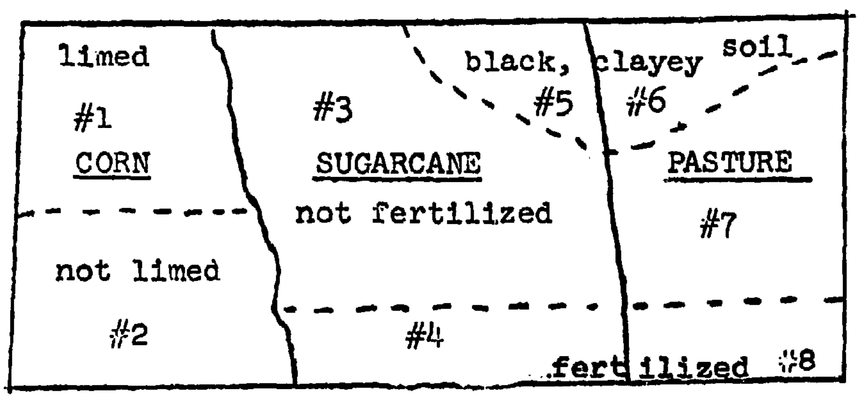
5. Sloppy lab work or poorly cared for equipment can really goof up the results.

In short, soil testing can provide valuable guides for fertilizer use if a good lab is available, but keep in mind that the results are ~~never~~ NOT completely accurate.

HOW TO TAKE A SOIL SAMPLE

Proper sampling is the most important yet weakest part of soil testing. Each 1/2-1 lb. soil sample you send in may be representing as much as 15,000 tons of soil. You can do a good job by following the instructions below:

Divide the land into sampling units: Start out by drawing a map of the land you plan to sample and divide it according to use. Then make a further division according to differences in soil color, texture, drainage, and past management. (fertilizer, liming, etc.). The final map might look something like this: (Sampling units are numbered)



If a sampling unit is much over 15 acres, it should be divided in half and each part sampled separately.

Taking the Samples: Most labs will want a 1/2-1 lb. sample from each one of the sampling units. This sample is a composite of 10-20 sub-samples taken at random locations within one sampling unit. Usually only a topsoil or plow layer sample is (top 6-9") is requested, although some labs may want a separate subsoil sample too. Take about 1/2 lb. of soil at each of the random sample locations (don't include the surface litter) and put these sub-samples (i.e. all those from one sampling unit) into a pail and mix well. Don't mix topsoil and subsoil samples together! A soil probe is a very handy tool for rapid sampling (see p. 18). When sampling pasture land, some labs will want the samples taken from the top 2" of soil. When sampling land in tree crops, sample only the soil under the tree canopies. Avoid taking soil from fertilizer bands or under animal droppings. Be sure to number the samples and the sampling units to avoid a mix-up. Never mix samples from different sampling units. If the samples are wet, they may be air dried but not oven-dried since excessive heating will result in a falsely high potassium reading.

Fill out the information sheet: The lab will provide an information form asking for data on the location, slope, drainage, cropping history, crop to be grown, previous and expected yields, and past applications of fertilizer and lime. This information must be given for each sampling unit. Send in the samples and information sheet at least a month before you need the results to make sure you'll get them in time.

How often should you soil test?: Under low rates of fertilizer (40-50 lbs. N, 30 lbs. P_2O_5, 0-40 lbs. K_2O per acre), fields should be sampled about once every 5 years. Under heavy fertilization, it's wise to sample every year or two. In the case of subsoil samples, retesting every 10 years is usually sufficient, since subsoil nutrient status is rather stable.

What about Portable Soil Test Kits?: Portable soil test kits costing from $10-$100 are available for determining available N, P, K plus soil pH and sometimes Ca and Mg and one or several of the micronutrients. However, they are not as accurate as laboratory soil tests, several of the reagents must be reordered every year, and the glassware is difficult to keep clean. It's also a much better idea for campesinos to get used to sending in samples to a soil lab rather than relying on the temporary use of your equipment.

II. PLANT TISSUE TESTS

The crop itself can be tissue tested in the field to measure the concentration of N, P, and K in the plant sap. Lightweight, compact kits are available from $10-$25, but some of the reagents must be reordered every year.

As with soil tests, tissue tests aren't completely accurate but can provide valuable supplementary information if performed by a person who knows how to interpret the results. Sometimes the level of nutrients in the plant sap may not be related to the nutrient content of the soil; insects, disease, and very wet, dry, hot or cold weather can all affect nutrient uptake. Another problem is that deficiencies of one nutrient like nitrogen can stunt crop growth and cause P and K to accumulate or "pile up" giving a falsely high reading. Tissue test kits come with detailed instructions on what part of the plant should be sampled at what stage of growth and how to interpret the results.

Total Plant Analysis: An increasing number of labs in the U.S. can run a total nutrient analysis on plant leafs. The plant material is dried and ground and then a spectrograph is used to rapidly determine the level of all the nutrients and several other elements that might cause plant toxicities. A few Latin American labs may shortly be offering this service; it is rather expensive, however.

Unlike soil testing which can be conducted well in advance, it may be too late to apply extra fertilizer by the time a tissue test is conducted.

III. FERTILIZER TRIALS

How a crop responds to various fertilizer treatments can give a good indication of fertilizer needs if the trials are properly conducted. Field trials get the campesinos involved and are educational so long as they are not overly complicated. One of the simplest methods is to have a few test strips (about 3-4 rows each) running through the field trying different rates and combinations of nutrients. You should have several strips of similar treatment in different locations in the field. You can base the different fertilizer treatments on soil test recommendations, trying both high and lower rates also.

Demonstration plots can also be set up, preferably with the help of campesinos on their own land. The F.A.O. (Food and Agric. Organization) has been running numerous fertilizer trials and demonstrations in Latin America during the past several years and PC Volunteers have helped set many of them up. The simplest demonstration in the program uses 4 plots: one with no fertilizer, one with just N, one with N & P, and one with N,P, & K. Some of the others can be tedious to set up and record and may be too complicated to have much educational value; they do supply valuable research information on which future fertilizer recommendations can be partly based.

Trials vs. Demonstrations: A fertilizer trial is designed to obtain statistically significant data on crop response to varying fertilizer treatments. This requires random replications of the different treatments plus careful measurement of plot size, plant population and amount of fertilizer, and harvest differences. Such trials should be run for 2-3 years to take into account the influence of other factors such as variations in rainfall, etc. A fertilizer demonstration is designed to show farmers the value of fertilizer and is much less complicated. The simplest and often the most effective type uses 2 plots, one with and the other without fertilizer You should soil test first to get some idea of the nutrients and amounts needed. They give the most dramatic results if run on low fertility land.

IV. SPOTTING VISUAL "HUNGER SIGNS"

Plants suffering from a severe nutrient deficiency often show certain symptomatic markings on the leaves. In addition, the fruit, ear, or stalk may be malformed or exhibit other abnormalities. While somewhat useful, this method has several drawbacks:

1. A nutrient deficiency can be serious enough to lower yields by 30-60% without the appearance of hunger signs. Plants have to be really starving before showing hunger signs. Even though the crop looks good, it can often be suffering from "hidden hunger".

2. Some hunger signs may be easily confused with eachother or with insect and disease damage. Nutrient deficiencies may mask eachother.

3. It may be too late to adequately correct deficiencies by the time hunger signs appear.

Nevertheless, a knowledge of hunger signs can be very valuable in spotting deficiencies of nutrients for which soil tests aren't available (like most micronutrients and sulfur).

In getting to know the common hunger signs, good visual illustrations as well as written descriptions are a must. Both of the following would be helpful:

1. Hunger Signs in Crops, 3rd ed., 1964; edited by H.W. Sprague. David McKay Co., New York, $15. The best reference on hunger signs; covers cereal crops, cotton, tobacco, grasses, legumes, vegetables, sugar cane, fruit crops, and grapes. Contains numerous color plates.

2. Modern Corn Production by Aldrich and Leng, 1965. F & W Pub. Co., 22 E. 12th St., Cincinnati, Ohio 45210, $12.50 (sometimes available at $9.75). Contains a chapter on common corn troubles with excellent written and visual descriptions of hunger signs as well as insects, diseases, and other problems.

"Hunger Signs" in Corn and Sorghum

NITROGEN: Young plants are stunted and spindly with yellowish-green foliage. In older plants, the tips of the lower leaves first show a definite yellowing which proceeds up the leaf midrin in a "V" shaped pattern, the leaf margins remaining green. In some cases, there's a general yellowing of the lower leaves. In severe deficiencies, the lower leaves soon turn brown and die, starting at the tips. This is called "firing" but can also be caused by drought.

PHOSPHORUS: Hunger signs are most likely to occur during early growth. Mild deficiencies usually only cause stunted growth without clear-cut leaf signs. More serious deficiencies cause a purplish color starting at the tips of the upper leaves; leaf tips may begin to die and turn brown. However, not all varieties of corn and sorghum may show this purplish color but sometimes a bronze coloration of the same pattern. These symptoms usually disappear after the plant reaches 18" or so, but yields will still be severely lowered. Corn ears from P deficient plants have irregular kernel rows, are somewhat twisted, and have imperfectly developed ear tips.

POTASSIUM: Deficiency signs are rarely seen before plants are 15" high. The margins of the lower leaves turn yellow and die, starting from the tip. Potassium deficient plants have short internodes and weak stalks. Slicing the stalk lengthwise often reveals a darkish brown discoloration at the nodes due to iron accumulation. Ears from K deficient plants are small and may have very pointed, poorly developed tips.

SULFUR: Stunted growth, delayed maturity, and a general yellowing of the leaves (as distinguished from N deficiency). However, sometimes the veins may remain green which can be mistaken for an iron or zinc deficiency; iron and zinc deficiencies are most often found in basic alkaline soils, whereas sulfur deficiencies are more common in acid soils.

MAGNESIUM: Most common in acid, sandy soils. A general yellowing of the lower leaves is the first sign. Eventually, the areas between the veins become light yellow to almost white while the veins remain fairly greem, which causes a striping effect. As the deficiency progresses, the leaves take on a reddish purple color along their edges and tips starting at the lower leaves and working upward.

ZINC: Corn shows very definite and easily recognized zinc deficiency symptoms. In severe cases, symptoms appear within 2 weeks after plants emerge. 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 remain green; the plants are stunted and have short internodes. Mild deficiencies may cause an interveinal striping similar to iron or manganese deficiencies. However, in Mn and Fe deficiencies, the interveinal striping runs the full length of the leaf, while in the case of Zn it occurs mainly on the lower half of the leaf.

Zinc deficiency in sorghum is similar to corn, except there is less interveinal striping, and a more definite white band formation is observed on the lower parts of the leaves. Zn deficiencies are most common at soil pH's above 6.8.

IRON: Most likely to occur above pH 6.8; sorghum is much more sensitive than corn to Fe deficiencies. Both crops will show an interveinal yellowing which extends the full length of the leaves (especially the upper ones).

Copper, manganese, boron, and molybdenum deficiencies are rare in corn and sorghum.

PART VI

USING FERTILIZERS

I. FERTILIZER ARITHMETIC

How to Follow Fertilizer Recommendations

Fertilizer recommendations are usually given in terms of lbs. or kgs. or nutrients per acre, hectare, or manzana, etc. It's then up to you to select the kind and amount of fertilizer that will fit the recommendation.

PROBLEM #1: Recommendations based on soil tests tell Juan to apply 75 lbs. N, 50 lbs. P_2O_5, and 60 lbs. K_2O per acre. The local ag store carries the following fertilizers: 14-14-14, 12-24-12, and 15-10-12. Which fertilizer should he choose and how much should he apply?

SOLUTION: Both 14-14-14 and 12-24-12 have the wrong nutrient ratio to fit the recommendation. Alittle math work will show that 500 lbs. of 15-10-12 will fit the bill (5 X 15 = 75 lbs. N, 5 X 10 = 50 lbs. K_2O, 5 X 12 = 60 lbs. K_2O).

However, in order to minimize leaching losses of N, it's usually best to split the nitrogen application and put on 30-60% at planting time along with all the P and K (they don't leach) followed by the rest of the N a few weeks later when the plant really needs it. Take a look at problem #2:

PROBLEM #2: Suppose soil tests show that Ernesto should apply 120 lbs. N, 60 lbs. P_2O_5, and 60 lbs. K_2O on his one manzana cornfield (1.73 acres). How could he best fit the recommendation if the local ag store had the following fertilizers available:

16-20-0	Ammonium sulfate (21% N)
15-15-15	Ammonium nitrate (33% N)
15-10-10	Urea (46% N)

SOLUTION: Remember that you want all the P and K but only part of the N applied at planting time. You could use 600 lbs. of 15-10-10 for the first application which would put on 90 lbs. N, 60 lbs. P_2O_5, and 60 lbs. K_2O. However, this puts on too much N too early when the small plants can't use it which means that leaching losses might be high. Using 400 lbs. of 15-15-15 would cut the first N application down to 60 lbs. while still supplying the needed 60 lbs. of both P_2O_5 and K_2O. The remaining 60 lbs. of N would be applied several weeks later, and any of the 3 straight nitrogen fertilizers could be used (about 130 lbs. urea, 180 lbs. ammonium nitrate, or 300 lbs. ammonium sulfate).

Don't expect to always be able to exactly follow a fertilizer recommendation, because the right combination of fertilizers might not be available. Remember also that fertilizer recommendations based on soil testing, field trials, and tissue tests are only approximately accurate in the first place. Try to get within 15-20% of the quantities recommended though. If you have to put on extra P to supply enough K or vice-versa, don't sweat it; K, and especially P, aren't readily leached and the excess will remain in the soil for use by future crops.

<u>PROBLEM #3</u>: Soil test results tell Paco to apply 90 lbs. N, 50 lbs. P_2O_5, and 60 lbs. K_2O per acre. What's the best way of following the recommendation if he can choose from the fertilizers below:

15-10-10	12-24-12
10-15-15	10-30-10
13-13-20	Urea (46% N)

<u>SOLUTION</u>: 400 lbs. of 10-15-15 would supply enough P and K plus about 45% of the N. In fact, this would put on 10 lbs. more P_2O_5 than called for, but P doesn't leach and will remain in the soil for succeeding crops. He could supply the remaining 50 lbs. of N using about 110 lbs. of urea a few weeks later.

Selecting the Most Economical Fertilizer

When comparing costs of fertilizers, what counts is the <u>cost per pound of plant nutrient</u> and <u>not</u> the cost per sack.

<u>PROBLEM</u>: Which of the fertilizers below is the most economical source of nitrogen?

Urea (46% N), $6.44/100 lbs.
Ammonium sulfate (21% N), $4.20/100 lbs.
Ammonium nitrate (33% N), $5.61/100 lbs.

<u>SOLUTION</u>: Per lb. of N, urea costs 14¢ ($6.44 ÷ 46), ammonium sulfate costs 20¢ ($4.20 ÷ 21), and ammonium nitrate costs 17¢. Therefore, urea is the cheapest source of nitrogen in this case.

Other factors aside from the cost per lb. of nutrient may sometimes be important. For example, even though ammonium sulfate is often more expensive per lb. of N than urea, its sulfur content make make it the better fertilizer for sulfur deficient soils unless a cheaper form of sulfur were available. On the other hand, ammonium sulfate is considerably more acid than urea in its effect on the soil, so you would have to apply more lime in the long run (see page 42).

Don't try to compare mixed fertilizers that have significantly different nutrient ratios by adding up the lbs. of nutrients and dividing this into the price. For example, it would be difficult to compare 10-30-10 and 17-17-17 in terms of cost even though they both contain about 50 lbs. of N + P_2O_5 + K_2O. That's because a 1:1:1 ratio may give better returns than a 1:3:1 ratio according to the crop and soil, or vice-versa. Also, N, P_2O_5, and K_2O each have a different price per lb. However, you could compare 10-10-10 and 15-15-15 since they both have the same nutrient ratio; the latter would usually be less expensive due to lower transportation and bagging costs per lb. of nutrient.

Mixing Different Fertilizers

At times it may be necessary to mix 2 or 3 different fertilizers together to obtain a certain nutrient ratio. Whenever possible, this should be avoided since it's more confusing and probably less economical than using an already prepared mixed fertilizer not to mention the extra work involved.

A sample fertilizer mixing problem is shown below:

PROBLEM: Suppose you needed a fertilizer with a 1:3:1 ratio but the local ag store only had 14-14-14 and single superphosphate (0-21-0) on hand. How could you combine these 2 fertilizers to obtain a 1:3:1 ratio?

SOLUTION: 100 lbs. 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 single super, you'd get a 1:3:1 ratio.

	N	P_2O_5	K_2O
100 lbs. 14-14-14 =	14 lbs.	14 lbs.	14 lbs.
134 lbs. 0-21-0 =	0	28	0
234 lbs.	14	42	14

You'd end up with 234 lbs. of fertilizer containing 14 lbs. N, 42 lbs. P_2O_5, and 14 lbs. K_2O which gives you the desired 1:3:1 ratio. In order to find out the actual formula (i.e. lbs. of nutrients per 100 lbs. of fertilizer), you'd divide by 2.34; this gives you a formula of about 6-18-6.

<u>Not All Fertilizers can be Mixed</u>: As shown below, not all fertilizers are compatible with eachother:

FERTILIZER MIXING GUIDE

	Potassium chloride	Potassium sulfate	Ammonium sulfate	Sodium nitrate & potasium 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			O
Sodium nitrate & Potassium nitrate	X	X	X			X	X	X	
Calcium nitrate	X	X	X	X		X	O	O	X
Urea	X	X	X	X	X		X	X	X
Single & triple superphosphate				X	O	X			O
Mono- & di-ammonium phosphate				X	O	X			O
Lime			O		X	X	O	O	

[ ] = fertilizers which can be mixed.

[X] = fertilizers which can be mixed only shortly before use.

[O] = fertilizers which can't be mixed for chemical reasons.

<u>Lime</u> in any form should not be mixed with fertilizers containing <u>ammonium</u> or part of the nitrogen will be lost as gaseous ammonia. <u>Lime</u> should also not be mixed with the <u>superphosphates</u>, <u>ammonium phosphates</u>, or any mixed fertilizer containing these water soluble forms of phosphate, because the lime will revert part of the P to insoluble form.

II. HOW AND WHEN TO APPLY FERTILIZERS

You can't expect good results from fertilizers unless you know how and when to apply them. There is no one best way to apply fertilizer since this varies with the nutrient(s) involved and the amount to be applied as well as with the particular crop and soil.

Nitrogen

Even though ammonium nitrogen is fairly resistant to leaching (see page 25), it's readily converted by microbes to leachable nitrate (the warmer the weather, the more rapid the conversion). The higher the rainfall and the sandier the soil, the greater the loss by leaching. The best way to reduce these losses is to apply the nitrogen in 2-3 applications during the crop's growth rather than making just one big application. The first application should be made at or around planting time, usually as part of a mixed fertilizer like 14-14-14, 12-24-12, 18-46-0, etc. The rest is applied later on in the growing season (when the plants can really use it) as one or two side-dressing of a straight nitrogen fertilizer like urea or ammonium sulfate. A good general rule is to apply 1/3-2/3 of the N in the first application.

Except in drier areas where there may not be enough rainfall to move the N down to the roots, straight N fertilizers don't have to be placed any deeper than ½-1" in the soil. However, when N is applied as part of an NP or NPK fertilizer, it should be placed 3-6" deep since both P and K move very little in the soil and need to be placed in the zone where most of the roots will develop.

Phosphorus

Unless a soil is already high in available phosphorus (very unlikely), it's important that some P fertilizer be placed in a band or hole near the seeds or seedlings. Young plants don't need a lot of P in terms of quantity but do need a high concentration of P in their tissues for maximum root development and vigor; at this early stage, their root systems aren't extensive enough to obtain the P they need unless some is placed nearby. Unlike nitrogen which is applied 2-3 times during the crop's growth to reduce leaching losses, all the P is usually applied around planting time or shortly after since it doesn't leach.

Since P is so immobile in the soil, it should be placed 3-6" deep to make sure the roots can get at it. In areas of uneven rainfall, the top 1-2" of soil often remains too dry for much root development which means that plants can't utilize the shallow placed phosphorus. Even in humid areas, most of the roots are found deeper than 2"; shallow placement of P may also discourage deep rooting, making the plants less resistant to drought. If P is applied broadcast (not a recommended method for low rates), it should preferably be plowed under rather than disced (harrowed) in, since discing will only move the fertilizer up and down in the top 2-3" of soil.

Minimizing Phosphorus Fixation: Low rates of P (less than 40-50 lbs. P_2O_5/acre) are usually much better utilized if placed in a band or hole near the seed or seedling. This not only stimulates early growth but also greatly reduces phosphorus fixation (see page 26) by minimizing the contact between the fertilizer particles and the soil. For top yields, however, there should be a good level of available P throughout most of the root zone; therefore, many farmers with enough capital often use a combination of localized placement of P near the seed (usually no more than 20-30 lbs. of P_2O_5/acre) and larger broadcast applications. Few campesinos have the money to afford broadcast applications and are much better off using localized placement alone, especially on soils with a high P fixing capacity. Localized placement of P may not give him maximum profit per acre but should give him maximum return per dollar which is what really counts when capital is limited (see page 87).

Carryover of Added Phosphorus: Only about 5-25% of the P applied will be used by the first crop. The other 75-95% remains tied-up in the soil in the form of relatively insoluble compounds with iron, aluminum, and calcium. A good part of this slowly becomes available to future crops; even in soils with a high capacity to fix P, much of the P will eventually become available. That's why crop responses to large broadcast applications of P are sometimes obtained as much as 10 years later. Take a look at the experiment below that was conducted in North Carolina on a soil with a high P fixing capacity and notice the residual effect of the large broadcast applications of P:

P Applied in 1956 (lbs. of P_2O_5/acre)	Corn Yield in 1964 (bushels/acre)
0	27
350	64
700	89
1400	114

Few campesinos could afford such large applications of P in one lump. U.S. farmers often make periodic broadcast applications of P (every 2-3 years) to maintain a good level of P in the root zone but usually always band a small amount near the seed to get plants off to a good start. Remember that applying P is like putting money in the bank and making small, gradual withdrawls.

Potassium

Potassium (K) is almost always applied at or near planting time, usually as part of a mixed fertilizer. K is much less mobile than nitrate but more so than phosphorus ( ), but leaching losses are seldom serious except on sandy soils. As with P, K should be placed 3-6" deep in the zone of maximum root development due to its relative immobility. That's another reason why both P and K are applied at or near planting time, since such deep placement might severely disturb the roots otherwise. On sandy soils, K can be applied in 2-3 applications to reduce leaching losses; this is also recommended for pastures to reduce "luxury consumption" of K (see p. [redacted] 82).

Large amounts of K are sometimes broadcast and plowed under before planting, but few campesinos have the money or equipment to do this. Such broadcast applications are very effective and may suffice for several years; they aren't recommended for sandy soils or those with a high K fixing capacity (less common in the tropics). Large broadcast applications of K may induce [redacted] magnesium deficiencies in some crops (see page 28) on soils with borderline Mg levels, but this is rare with corn

Since about 2/3 of the plant's K is found in the leaves and stems vs. about 1/3 in the ear, pod, or fruit, returning crop residues to the soil is a good way to reduce the need for K fertilizer: About 1/2-2/3 of the K in potato, sweet potato, yuca (cassava), and taro plants is found in the root or tuber itself, however.

Sulfur

Sulfur is usually applied as part of a sulfur bearing fertilizer like single super, ammonium sulfate, ammonium phosphate sulfate (16-20-0), or potassium sulfate, etc. The application method is dictated by the other principal nutrients in the fertilizer. Sulfur is rather susceptible to leaching, especially in sandy soils.

Calcium and Magnesium

Calcium is more often applied in the form of a liming material (limestone, burned lime, etc.) to lessen soil acidity than to control a calcium deficiency; even very acid soils often have enough calcium as far as plant needs are concerned, although soil pH may be too low for best growth. To be effective, the liming material must be broadcast and plowed under several months in advance of planting (see pages ~~92-96~~ 95-99) on liming soils).

Magnesium deficiencies are usally corrected by applying dolomitic limestone ($CaCO_3 \cdot MgCO_3$) or a magnesium containing fertilizer like potassium magnesium sulfate.

Both Ca and Mg are fairly resistant to leaching since they have a + charge and are attracted to clay and humus particles. Large applications of acid forming fertilizers (see pages 41-42) will speed up this loss, however.

Micronutrients

Soil applications of manganese and iron are often ineffective since they're easily converted to unavailable forms in the soil, especially at high pH's (above 6.8); such soil tie-up can be reduced by using chelated forms of these nutrients or by making foliar applications with sprays. All the micronutrients can be applied as sprays which is often more convenient than making soil applications, although care must be taken to avoid leaf burn at high rates. Zinc can be banded near the seed or heavier rates may be broadcast. Boron may be broadcast or be mixed with other fertilizers and banded near the seed on row crops (rates of more than 1 lb. actual boron per acre may injure germinating seeds of some crops like corn if B is banded). Molybdenum is sometimes applied to the seed itself.

If micronutrient deficiencies are suspected, it's best to consult a competent agronomist concerning the best formulation and application method for the particular crop and soil.

APPLICATION METHODS

There are 6 common ways to apply fertilizer:

1. Broadcasting
2. Placement in a separate band or hole near the seed or plant
3. Placement under the seed
4. Placement with the seed
5. Spraying the foliage
6. Application through the irrigation water

1. Broadcasting

A common method for applying high rates of nutrients. The fertilizer is applied broadcast over the soil surface and hoed in, disced in, or plowed under before planting time. P and K should preferably be plowed under rather than harrowed in to assure that they're placed deep enough where the roots are. Topdressing refers to surface broadcast applications on established pastures or small grains.

The pros and cons of broadcasting are listed below:

Pros:

1. Gives a better distribution of nutrients in the root zone which is more conducive to high yields than localized placement.

2. Labor needs can be better distributed since much of the fertilizer can be applied before planting time; large broadcast applications of P and K may last for several years (see pages 55-56).

3. High rates can be applied without danger of burning the plants.

Cons:

1. Broadcasting maximizes the fixation of fertilizer phosphorus by exposing fertilizer particles to maximum contact with the soil. The same is true with potassium on soils with high K fixing capacities (uncommon in the tropics).

2. You fertilize the weeds as well as the crop.

3. Low rates of fertilizer will be "spread too thin" if broadcast.

4. Plants receive no early growth stimulation unless a combination of broadcasting and banding is used.

5. Campesinos may not have the equipment for uniform spreading or for plowing under P and K.

2. Placement in a Separate Band or Hole Near the Seed or Plant

Fertilizer can be placed in a continuous band or "rope" along the row near the seeds (usually 1-2" below and 2-3" to the side of the seeds). If seeds are planted much more than a foot or so apart, placing the fertilizer in a hole or partial circle near the seed or group of seeds may be easier, especially if the soil is very hard. Fertilizer can also be applied to growing plants by placing it in a shallow band (1-2" deep) so as not to injure roots or it can be placed deeper (desirable for P and K) by putting it in a small hole. In general, banding will usually give better results than hole placement by giving better distribution of fertilizer. Tractor drawn planter-fertilizer applicators are available that will precisely band fertilizer but are rather expensive. Horse drawn equipment is quite a bit cheaper. The S.L. Allen Co. (5th St. & Glenwood Ave., Philadelphia, Penn.) puts out a "Planet Jr." fertilizer drill ($50-$75) that can be pushed by hand (on loose enough soils) and will band fertilizer.

Pros:

1. Placement near the seed stimulates early growth and vigor and gives plants a jump on weeds.

2. Small amounts of fertilizer are more efficiently used than when broadcast.

3. The fixation (tie-up) of P and K is minimized since the fertilizer particles have less contact with the soil than when broadcast.

4. You don't feed the weeds.

5. Ideal for plants with less extensive root systems like lettuce, cabbage, potatoes, tobacco, and cotton.

Cons:

1. On low fertility soils, it's difficult to produce top yields with localized placement of fertilizer alone. Many farmers with enough capital use a combination of broadcasting high rates of fertilizer and banding smaller amounts near the seeds.

2. Localized fertilizer placement doesn't stimulate extensive root development as much as broadcasting.

3. Placement under the Seed

Placement of fertilizer under the seed is not recommended unless you're using a straight phosphorus fertilizer. Fertilizer placed below the seed will move upward with water as the soil dries and may injure seeds or transplants. However, straight P fertilizers are safe to use but should still be separated from the seed by 1 inch of soil. Placement of P under the seed or transplant often gives excellent results on tap-rooted crops like tomatoes, cotton, tobacco, and onions. On the other hand, sideband placement of P is better for crops with a fibrous root system like corn, sorghum, and small grains

4. Placement with the Seed

This type of placement is sometimes called "pop up" since it stimulates early growth (although germination may be delayed). Since phosphorus provides most of the early growth stimulus, the fertilizer should have a high ratio of P to N and K like 1:3:1 or 1:4:1. No more than 10 lbs. of N + K_2O should be applied per acre with the seed or severe burning may results (P itself has little burning effect). Usually no more than 50 lbs. of a fertilizer like 6-24-12 is applied per acre with the seed. Di-ammonium phosphate or urea should not be used since they release ammonia which may harm seeds.

It's doubtful that placement with the seed is any more effective than band or hole placement in terms of final yields. In most crops the roots will reach the banded fertilizer only a few days after they would reach the pop up fertilizer. Also, the amount of pop up than can safely be applied is only enough to have a temporary effect; if additional fertilizer is not broadcast previously or banded, the plants may "poop out".

(See under Corn on page 66 for a partial modification of this method that has been used successfully).

5. Spraying the Plants

This is a common method of applying micronutrients, especially manganese and iron which are so easily tied up in the soil.

Foliar applications of N, P, and K: Foliar application of macronutrients is seldom practical since numerous sprays would be needed to supply the large amounts needed. Another problem is that young plants have too small a leaf area to catch the spray. Various brands of liquid N-P-K fertilizers designed for foliar application are on the market but are considerably more expensive per pound of nutrient than solid forms and are rarely worth it. Research has shown that foliar applications will "green up" the plants more than soil applications but that final crop yields are about the same.

One exception is the foliar application of urea to bananas, often in conjunction with the routine application of fungicides and insecticides; in this case, enough applications can be made to apply considerable quantities of N. Studies have also shown that foliar applications of P to coffee may be very beneficial on soils with a high P fixing capacity.

6. Application through the Irrigation Water

Very convenient in irrigated areas but has some serious disadvantages. It's hard to get an even distribution of water (and therefore fertilizer) on the land, and irrigation may be delayed by excessive rains. This method also maximizes the fixation of P and K.

APPLYING FERTILIZERS ON IRRIGATED SOILS

In the case of furrow irrigation, the fertilizer should be placed at or below the level that the irrigation water reaches in the furrow. Such placement enables mobile nutrients like nitrate and sulfate to be moved sideways and downward toward the roots; if placed above the water line, they will be moved upward by the capillary rise of water out of the reach of the roots. Another point is that the placement of immobile nutrients like P and K above the water line puts them in a zone with few roots since it's only intermittently moist.

HOW TO AVOID FERTILIZER "BURN"

Many fertilizers will cause "burning" if placed too close to the seed or plant. This is caused by a high concentration of soluble fertilizer salts around the roots which prevents them from absorbing sufficient water, and the plants will wilt and dry up. If burning symptoms do appear, a heavy watering or irrigation will help leach the soluble salts away from the roots. However, the danger of burning is small as long as fertilizer is placed 2" to the side of the seed if banded or 3" to the side of the seed if placed in a hole. Plants are more susceptible to burning on sandy soils than clayey soils.

Fertilizers vary greatly in their soluble salt content. Nitrogen and potassium fertilizers are much more likely to cause burning than straight phosphorus fertilizers. The table below shows the relative "salt index" of common fertilizers per lb. of N, P_2O_5, and K_2O (not per lb. of fertilizer). The higher the number, the more careful you have to be about placement.

Fertilizer	Analysis	Salt Index per lb. of plant nutrient
Sodium nitrate	16% N	100
Potassium nitrate	13%N, 46%K_2O	88
Ammonium sulfate	21%N	54
Ammonium nitrate	33%N	49
Mono-ammonium phosphate	11%N, 48%P_2O_5	31
Potassium chloride	60%K_2O	32
Urea*1	46%N	27
Di-ammonium phosphate	21%N, 53%P_2O_5	26
Potassium sulfate	54%K_2O	14
Single superphosphate	20%P_2O_5	6.5
Triple superphosphate	48%P_2O_5	3.5

*1. Urea and di-ammonium phosphate may cause more injury than ammonium sulfate, ammonium nitrate, and mono-ammonium phosphate since they release free ammonia.

HOW TO APPLY A GIVEN AMOUNT OF FERTILIZER OVER A GIVEN AREA

When fertilizer is applied by hand, it's hard to apply the required amount uniformly over a large area. The table below will be of some help:

Distance between rows	Approximate amount of fertilizer needed per 25 ft. of row on the basis of: 200 lbs./acre	400 lbs./acre	600 lbs./A
12"	.12 lbs.	.25 lbs.	.35 lbs.
18"	.18	.37	.55
24"	.25	.50	.75
30"	.30	.60	.90
36"	.37	.75	1.1
42"	.43	.85	1.25

When fertilizer is to be placed in a hole or partial circle near the plant or group of plants instead of being banded it's easy to calculate the individual dosages. For example, if a campesino has 4000 hills of corn (groups of plants) per acre and wants to apply 300 lbs. of 16-20-0 per acre, he'd need about 1.2 ounces per hill (300 X 16 oz. = 4800 oz. 4800 oz. ÷ 4000 = 1.2 oz.). Then look for a container that would hold this quantity of fertilizer and use it as a measuring device (a large spoon or shot glass might work). You can weigh out the individual dosage on a small scale (most "farmacias" or post offices will have one).

APPLICATION METHODS FOR INDIVIDUAL CROPS

In the next pages, application methods are given for the following crops:

Corn	Cassava (yuca, manioc)
Sorghum	Sweetpotatoes
Rice	Potatoes
Beans	Vegetables
Soybeans	Pastures
Peanuts	Coffee

Suggusted fertilizer rates are also given, but should only be used as very rough guides. In most cases, they are only about 1/3-1/2 of what's needed for top yields but should produce about the maximum return per dollar spent which is what a campesino with limited capital should really be after (see pages 90-91). Use soil testing and field trials whenever possible to help determine the absolute and relative amounts of nutrients needed (see pages 44-49).

CORN

Depending on the variety and temperature, corn matures in about 90-130 days in the 0-3000 ft. zone of the tropics but may take up to 8-12 months at high altitudes (7000 ft. on up). Yields of shelled grain under varying conditions are shown below:

	Lbs./acre	Lbs./manzana	Kgs./hectare
Top farmers in U.S. Corn Belt	9000-12,000+	15,500-21,000+	10,000-13,500+
U.S. Average	4500	8000	5000
Average yield in underdev. countries	850-1250	1500-2200	950-1400

Even low rates of fertilizer like 30-40 lbs. N, 20-30 lbs. P_2O_5, and 30-40 lbs. K_2O per acre can double or triple yields when starting from a low base. As a rough rule of thumb, yields of shelled grain should be increased by 50-100 lbs. for each 2 lbs. of N + 1 lb. of P_2O_5 applied provided that moisture and other nutrients aren't deficient, insects and weeds are adequately controlled, an improved variety used, and that there are no serious soil problems. Returns of $2-$6 per $1 of fertilizer are common when the "package" approach of combining several good management practices is used. However, the response from fertilizer also depends very much on the kind and amount used plus how and when it's applied.

N, P, and K are the most commonly deficient nutrients, although little or no K may be needed on many medium to fine textured soils of volcanic origin.

Nitrogen: N is needed for vegetative growth and for protein and chlorophyll formation; the peak demand for N in the corn plant occurs during the period from 3 weeks before until 2 weeks after tasseling. Remember that leaching losses of N are a problem on all soils, especially in coarse textured soils under high rainfall. Such losses can be reduced by applying 1/3-2/3 of the N at planting time and side-dressing the rest when the plants are about knee high.

Phosphorus: P plays an important role in root development, stalk strength, and grain formation. Remember that P is virtually immobile in the soil and should be placed 3-6" deep to assure that it will be available to the roots. At least part of the P should be placed in a band or hole near the seeds to assure that the small root systems of the young plants will be able to absorb the amount needed. Low to medium rates of P (up to 50-60 lbs. P_2O_5 per acre, 85-100 lbs./manzana, or 55-65 kg./hectare) are much better utilized if placed in a band or hole near the seeds rather than being broadcast. Such localized placement reduces P tie-up by minimizing the contact between the fertilizer particles and the soil and gets the young plants off to a good start. At rates over 70 lbs. P_2O_5 per acre (125 lbs./manzana, 80 kgs./hectare), 2/3 of the P should be broadcast and worked in with a plow or hoe before planting and the remaining 1/3 applied in a band or hole near the seeds at planting time.

Potassium: K influences the general vigor of plants and is important for root growth, stalk strength, and disease resistance. K is rather immobile in the soil, and leaching losses are seldom serious except in sandy soils. As with P, K should be placed 3-6" deep due to its relative immobility.

Secondary and Micronutrient Needs: Sulfur deficiencies in corn are rare and occur mainly in sandy soils under high rainfall or in cases where fertilizers containing little or no sulfur have been used for several years. Magnesium deficiencies are uncommon except in very acid soils (below pH 5.5) and can be corrected by liming the soil to pH 6.5 with dolomitic limestone (combination of calcium and magnesium carbonates) or by spraying the plants with 15-20 lbs. epsom salts ($MgSO_4 \cdot 7H_2O$) per acre in 100 gallons of water or by side-dressing the crop with a soluble magnesium salt containing 20-25 lbs. of magnesium per acre (epsom salts contain about 10% Mg and potassium magnesium sulfate about 11% Mg). Except for zinc, corn is not particularly susceptible to micronutrient deficiencies. Such deficiencies are most likely to occur above a pH of 6.8 (except for molybdenum) or in sandy or organic (peat or muck) soils. Large applications of P may lower the uptake of zinc below the critical level in soils already low in zinc to begin with. Zinc deficiency can be confirmed by spraying 10-20 plants with a solution of 1 teaspoonful of zinc sulfate in a gallon of water; if there is a zinc deficiency, new leaves will be a normal green when they emerge (see pp. 48-49 for "hunger signs"). From 2-10 lbs. of zinc per acre (3.5-17.5 lbs./manzana, 2-11 kg./hectare) are usually needed to correct a zinc deficiency (zinc sulfate contains 26-36% Zn) and is usually mixed and applied with the regular fertilizer; one application may last several years. Never apply micronutrients as "insurance" since there is a fine line between toxic and deficient levels. If you suspect micronutrient problems, consult a competent agronomist.

Corn grows best within a pH range of 5.5-7.5. If the pH is below 5.5, consider liming, preferably with dolomitic limestone, but first read over the section on liming (pp. 95-99). Overliming a soil can leave the campesino worse off than before by increasing the liklihood of micronutrient deficiencies, tieing up soil phosphorus, and speeding up the loss of soil humus.

Determining Fertilizer Needs

A laboratory soil test is the best guide to what's needed in terms of N, P, K, magnesium, and lime; tests for sulfur and most micronutrients are unreliable. Check also with the Ministry of Agric. for possible data on field trials conducted in your area. To be meaningful, a field trial must be carefully designed and carried out, and the results apply only to the particular type of soil on which the trial took place . The diagnosis of visual "hunger signs" is not a very helpful method by itself, since plants often suffer from "hidden hunger" and usually don't exhibit visual symptoms unless the deficiency is severe. "Hunger signs" are also easily confused with eachother or with insect and disease damage (see pp. 48-49 for "hunger signs" in corn).

If soil test results aren't available, use the following rates as a rough guide: at least 40 lbs. N, 25 lbs. P_2O_5, and 30-40 lbs. K_2O per acre. Due to the law of diminishing returns, the campesino with limited capital is usually better off applying low to medium rates of fertilizer on a larger area of land rather than a high rate on a smaller area (unless land is limited or rental rates extremely high). The table below gives a rough idea of low, medium, and high rates of N, P_2O_5, and K_2O in lbs. per acre and per manzana (1.73 acres):

	LOW		MEDIUM		HIGH	
	lbs./acre	lbs./mz.	lbs./acre	lbs./mz.	lbs./acre	lbs./mz.
N	30-50	50-85	60-90	100-160	100+	175+
P_2O_5	20-30	35-50	40-60	70-100	75+	130+
K_2O	30-40	50-70	50-70	85-125	80+	140+

(kgs./hectare = 1.12 X lbs./acre)

APPLICATION METHODS FOR CORN

The 2 application methods below will give good results, although Method 2 is the best one for most soils.

Method 1: A "one shot" application of an NP or NPK fertilizer when corn is about 6" tall.

Method 2: An application of 1/3-2/3 of the N + all the P and K at planting time, followed by the rest of the N as a side-dressing when corn is approaching knee height.

Method 1 ("one shot")

The "one shot" method usually won't give as good results as making 2 applications, but it may be the best for those campesinos who lack capital and aren't very familiar with fertilizers.

Kind of Fertilizer: Use a fertilizer with a 2:1:2, 2:1:1, or 2:1:0 ratio ($N:P_2O_5:K_2O$) depending on how much K is needed. A 1:1:1 or 1:1:0 ratio can be used, but you'll be putting on more P than is really needed in order to supply enough N; don't sweat this since much of the extra P will be available to future crops.

Time and Method of Application: Putting the fertilizer on early would get the plants off to a good start, but a lot of N may be leached out of the root zone before the time of maximum need. On the other hand, if you wait too long, you won't get the P and K on early enough. The best compromise is to apply it when the plants are about 6" tall. Remember that P and K should be placed deep where the moisture and roots are. You can use a pointed stick about 1" in diameter to make a hole about 4-6" deep about 5-6" from the plant or group of plants. Making 2 holes on opposite sides may give better results but is time consuming. In very sandy soils or very wet climates, the fertilizer only has to be placed 2-3" deep. In very clayey soils or under low rainfall, the fertilizer can be applied at planting time in a band 2" below and 2" to the side of the seeds or in a hole 3-4" from the seed(s).

Method 2 (two applications)

Method 2 should give significantly better results, especially under high rainfall or in coarse textured soils, and it should be used whenever possible.

1st Application: Use an NP or NPK fertilizer with a nutrient ratio that will allow application of all of the P and K but only 1/3-2/3 of the N. Apply the fertilizer at planting time in a continuous band 2" below and 2" to the side of the seeds or in holes 4-6" deep and 3" from each group of seeds. Hand pushed or animal drawn fertilizer banders or bander-planters are available but may be too expensive ($50-$150) for most campesinos. In the case of hole placement, a planting stick can be used to make the hole for the fertilizer or an implement could be designed that would make separate holes for the seed and fertilizer simultaneously. A time saving and economic alternative would be to make "V" shaped furrows 2-4" deep (the usual planting depth of corn) on a plowed field using a homemade, animal drawn implement (the furrows made by an ox drawn wooden or steel tipped plow might be used instead). The fertilizer is then sprinkled down the length of the furrow followed by dropping the seeds in the same furrow and covering them with a sideways movement of the foot. The seeds won't be in contact with enough fertilizer to cause burning if rates are kept below 100-125 lbs. N + K_2O per acre (175-215 lbs./manzana) (P has little burning effect). However, di-ammonium phosphate (18-46-0, 16-48-0, 21-53-0) may cause burning through the release of free ammonia at rates above 30-40 lbs. N per acre (50-70 lbs./manzana) if this method is used. The furrow method of placement gives a much better distribution of nutrients than hole placement and is much less time-consuming, although the P and K may be placed alittle too shallow for best utilization. However, the next plowing will help move the P and K down deeper for the next crop.

2nd Application: Apply the rest of the N as a side-dressing when the plants are about knee high using a straight N fertilizer such as urea, ammonium sulfate, or ammonium nitrate. N moves readily downward once converted to mobile nitrate so it only has to be placed ½-1" deep; deeper placement is not only unnecessary but might also prune the roots. By the time corn is knee high, the roots have usually crossed eachother in the middle of the row, so placement right down the middle is usually just as effective as closer placement unless the rows are wider than 38-40". Side-dressing down the middle of every other row is usually just as effective as covering every row. In very sandy soils, apply 1/3 of the N at planting, 1/3 at knee height, and 1/3 at silking time.

NOTE: When growing corn under furrow irrigation, the N must be placed below the water line to avoid its being carried upward and away from the roots by capillary water movement.

SORGHUM

The same fertilizer applications methods and rates given above for corn can be used for sorghum. However, sorghum seeds and seedlings are more sensitive to fertilizer burn than corn which means the "V" furrow method of application is probably not feasible. Early, localized placement may be more important with sorghum since the seedlings and their root systems develop more slowly than those of corn. Once developed, however, the root system is more extensive than that of corn, and sorghum plants are better extractors of nutrients and water. Sorghum is very sensitive to iron deficiencies which are most likely to occur above a pH of 6.8. Deficiencies can be corrected by applying 10-15 lbs. of ferrous sulfate ($FeSO_4 \cdot 7H_2O$) per acre in 20-50 gallons of water 10-15 days after seedling emergence; repeat in about 10 days if symptoms persist. See pages 48-49 for "hunger signs" in sorghum).

Where 2 cuttings of sorghum are made, about 1/2 of the N should be applied at planting time along with all the P and K, followed by the remainder of the N shortly after the first cutting.

RICE

Dryland vs. Irrigated Rice

A large part of Latin America's rice is not grown under flooded conditions but relys entirely on rainfall for moisture. Such "dryland" rice can only be successfully grown on rather poorly drained, fine textured soils where a high moisture content can be maintained. Yields of irrigated (flooded) rice are usually 50-60% higher than those of dryland rice since flooding provides a more ideal environment for the roots as well as improving the availability of certain nutrients, particularly phosphorus (flooding often provides better weed control, too). However, satisfactory production of irrigated rice requires level land, plenty of water, a system of canals and dikes, and soils impermeable enough to maintain a 6-10" layer of water over them without excessive leaching. For these reasons, most campesino grown rice is not flooded.

High N Response vs. Low N Response Varieties

Rice varieties can be divided into 2 groups based on their response to nitrogen. Low nitrogen response varieties are tall growing (usually over 5 ft.) and leafy. They respond to increasing rates of N by growing taller and producing more tillers (stems from the same plant). This causes lodging (tipping over) plus a mutual shading of the added tillers, which results in few seed heads being produced. Such varieties seldom respond well to more than 20-30 lbs. of N per acre. Most "criollo" (native) varieties belong to this class.

High N response varieties are generally short strawed (3-4½ ft. tall) and produce a high number of seed producing tillers. They respond to increasing rates of N not by growing taller but by producing more effective tillers (ones that produce heads). Improved varieties such as Blue Bonnet, Belle Patna, Nilo, Dima, Blue Belle, Dawn, IR-8, and IR-5 give a profitable response up to 100 lbs. of N per acre under good management.

Placement and Timing of Fertilizer

Dryland and Direct Seeded Flooded Rice: The first application should be an NP or NPK fertilizer applied before, at, or shortly after planting time. If applied before planting, it should be broadcast and disced or plowed into the soil. If applied at planting time or shortly after emergence. the fertilizer can be placed 2" to the side of the row and 2" deep. Deep placement of P and K is not necessary with rice since the plants have a large number of roots near the surface which is almost constantly moist or flooded. The rest of the N can be applied 35-50 days after planting as a side-dressing down the middle of the rows about 1" deep. When high rates of N are applied (more than 60 lbs. per acre), about 25% should be applied at planting, 50% just prior to tillering stage, and the remaining 25% just before heading. Excessive N during tillering should be avoided to reduce the danger of lodging and mutual shading. An ammonium form of nitrogen (or urea) should be used for flooded rice and placed 1-2" deep in the soil to avoid losses by denitrification (see below).

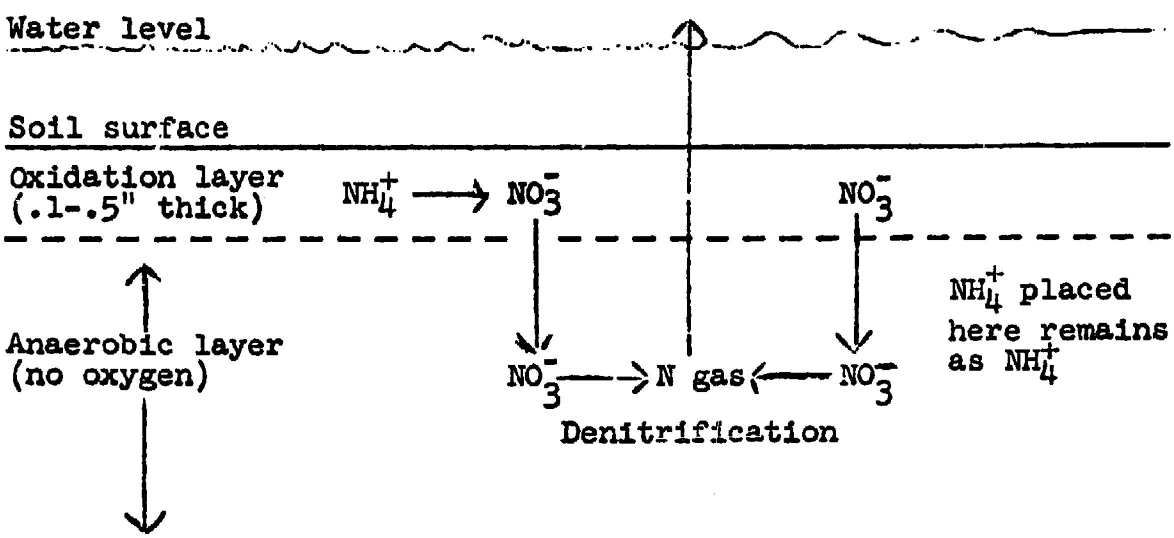
Transplanted Rice: Most campesino grown flooded rice is transplanted rather than direct seeded to facilitate weed control and because the smaller farmer is often unable to prepare a good enough seedbed over his entire field for flooded rice. Transplanting takes place about 25-30 days after emergence for short maturing varieties (90-120 days) and 30-50 days after emergence for later maturing varieties (125-185 days). An NP or NPK fertilizer can be applied shortly before transplanting by broadcasting followed by discing or plowing it in; alternatively, it can be applied within a few days after transplanting by placing it 1-2" deep along the row about 3-4" from the plants. Most nurseries are not fertilized, but responses can sometimes be obtained by applying a fertilizer high in P; rates of 4.5-6 grams N, 12.5 grams P_2O_5, and about 13.5 grams K_2O per square meter are commonly recommended for trial on nurseries (this is equal to about 1½-2 ounces N, 4½ oz. P_2O_5, and 5 oz. K_2O per 100 sq. feet).

After the initial application of an NP or NPK fertilizer around transplanting time, the rest of the N is applied in one or two applications (see above under dryland and direct seeded, flooded rice).

Placement of N under Flooded Conditions: Urea or an ammonium form of N should be used with flooded rice and placed 1-2" deep to avoid losses by denitrification (conversion to nitrogen gas). This is because a flooded rice soil contains two layers— one with and one without oxygen. The surface 0.1-0.5 inches of soil make up the aerobic layer and below that is the far larger anerobic layer without oxygen. Ammonium forms of N (including urea) have the advantage of being held by the clay and humus particles (see page 26) as opposed to nitrate N which is very susceptible to leaching. However, if ammonium or urea nitrogen is in the aerobic zone, there will be enough oxygen to convert it to nitrate (NO_3^-). The nitrate then leaches down into the anaerobic zone where oxygen hungry bacteria steal its oxygen and convert it to nitrogen gas which is lost to the atmosphere. If the ammonium or urea nitrogen is originally placed in the anaerobic zone it will remain as ammonium and be held against leaching; the ammonium (NH_4^+) doesn't contain any oxygen and therefore can't be denitrified by oxygen hungry bacteria.

Numerous studies have shown that broadcasting N fertilizer over the water is only about half as effective as placing it 1-2" deep in the soil which puts it in the anaerobic zone. Such placement is possible by draining the field temporarily; it should then be reflooded a day or so after application to prevent the ammonium from being converted to nitrate under aerobic conditions. When urea is used, it's advisable to wait 1-2 days before reflooding to allow the urea nitrogen (not held by soil) to be converted to ammonium (NH_4^+).

Diagram of a Flooded Rice Soil



Determining Nutrient Needs for Rice

Soil testing and field trials will be your best guides. N and P are the two most important nutrients. K deficiencies are not widespread on rice soils, probably since most of them are high in clay. Deficiencies of secondary and micronutrients are not common, although iron and manganese deficiencies sometimes occur at soil pH's above neutrality (7.0). Rice is fairly tolerant of soil acidity down to pH 5.0. A point to remember is that flooding causes a slight rise in soil pH.

BEANS

Although beans are a legume, they still do require some fertilizer nitrogen. An NP or NPK fertilizer can be used at planting time applied in a band 2" below and 2" to the side of the seed. The furrow method used with corn is not recommended for beans since they're sensitive to fertilizer salt injury. If beans follow well fertilized corn, fertilizer may not be necessary. In fertilizer demonstrations conducted by the Food and Agric. Organization throughout Central America during 1961-63, a 40-40-0 or 40-40-40 treatment (= lbs. of N, P_2O_5, and K_2O per acre) gave yield increases ranging from about 20% to 140%. A NITROGEN SIDE-DRESSING IS GENERALLY NOT NECESSARY.

Beans have a fairly high sulfur requirement, so it's a good idea to include a sulfur bearing fertilizer (see page 40). Beans are sensitive to manganese and zinc deficiencies which are most likely to occur above a pH of 6.8. MANGANESE TOXICITIES ARE COMMON BELOW PH 5.5.

SOYBEANS

Mature, dry soybeans range from 14-24% in oil and 30-50% 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, the making of margarine, and for industrial purposes. Unfortunately, most of the high yielding varieties are high in oil and rather unpalatable for humans. The meal remaining after oil extraction by crushing or with solvents is often the main source of protein in poultry and swine rations. Raw soybeans contain a trypsin inhibitor (trypsin is an enzyme needed for protein digestion) which first must be deactivated by heating (this is done in the manufacture of soybean meal).

Soybean varieties are photosensitive in that flowering and pod formation are stimulated by short day lengths. If a variety is moved southward to an area of significantly shorter daylength, flowering and pod formation will begin long before sufficient vegetative growth has occurred, and yields will be poor. At present, most soybean varieties grown in tropical Latin America come from the Southern U.S. since differences in daylengths between these two areas aren't significant enough to cause serious yield reductions.

The 1966 average U.S. soybean yield was 1500 lbs. per acre (2600 lbs./manzana, 1700 kg./hectare). Yields of 3000-3600 lbs./acre are common with over 6000 lbs./acre obtained in yield contests. A realistic yield goal for tropical Latin America would be 1800-2400 lbs./acre (3100-4200 lbs./manzana, 2000-2700 kgs./hectare).

Fertilizer Needs and Application

Soybeans are a legume whose particular strain of associated Rhizobia bacteria are very efficient nitrogen fixers (see page 6). Fertilizer nitrogen is usually gives no response and is a waste of money since it only depresses the nitrogen fixing activities of the bacteria who use the fertilizer N instead. Some farmers will apply low rates of N (like 10-20 lbs. per acre) feeling that it gets the young plants off to a good start before the Rhizobia have become active enough to supply nitrogen. However, this is not a proven practice and would certainly not be needed when soybeans immediately follow well fertilized corn as a 2nd wet season crop.

Soybeans grow best within a pH range of 6.0-7.0. More acid soils depress the activities of the Rhizobia and can also cause aluminum and manganese toxicities (see page 23) as well as molybdenum deficiencies.(Mo is also needed by the Rhizobia themselves). Above a pH of 7.0, phosphorus and micronutrient deficiencies (except Mo) are more likely.

Soybeans will respond well to P and K on soils low in these nutrients; response is much less likely if soybeans follow well fertilized corn. The fertilizer should be applied in a band 2" below and 2" to the side of the seeds. Soybeans are very sensitive to fertilizer salt injury, so don't place the fertilizer with the seed (it will also kill the Rhizobia on innoculated seed).

Although sensitive to manganese toxicity, soybeans have a relatively high requirement for manganese, and deficiencies are not uncommon, especially at soil pH's above 6.5. Manganese can be applied by spraying the plants or can be mixed with the banded fertilizer in cases of a deficiency. Soil applications of 5-15 lbs. manganese per acre or foliar applications of 1-5 lbs. per acre will correct deficiencies (manganese sulfate contains about 26% manganese).

Molybdenum is needed by both the plant and the Rhizobia bacteria, but deficiencies only occur on acid soils. Liming the soil to a pH of 6.0 will usually correct a deficiency; instead of liming, the seed can be treated with molybdenum at the same time it is innoculated. Add 1/2 ounce of sodium molybdate or ammonium molybdate to 1/2 pint 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 before the seed coats are completely dry.

Magnesium deficiencies are only found in soybeans grown in soils with a pH much below 6.0. Liming with dolomitic limestone to a pH of 6.0-6.5 will correct deficiencies. Don't overlime!

Seed Innoculation: Unless soybeans have been grown on the same soil for several years, seed innoculation is essential to assure that the proper strain of Rhizobia is present. The innoculant is a dried powder which contains the living bacteria and comes in a sealed package or can. The seed is placed in a basin and moistened with water to help the innoculant stick, and the correct amount is mixed with the seed. The innoculated seed should be seeded within 4 hours and should not be exposed to sunlight or the bacteria may be killed. The "Nitragin" brand of soybean innoculant has given good results in the tropics. Be sure the innoculant you obtain is specifically for soybeans. You can examine plants to check for proper nodulation (see under peanuts).

PEANUTS

Mature, shelled peanuts contain about 40-48% oil and 25-30% protein. One ton of cleaned and unshelled peanuts yields about 530 lbs. of oil, 820 lbs. of meal, and 650 lbs. of shells. Peanuts mature in 4-5½ months and prefer well drained soils with a medium to coarse texture (the peanut "pegs" have difficulty entering clayey soils). Average yields without improved practices run from 500-1000 lbs./acre (850-1700 lbs./manzana, 550-1000 kgs./hectare). With improved practices, yields average about 1500-2000 lbs./acre (2500-3500 lbs./manzana, 1700-2200 kgs./hectare) and can run as high as 4000-5000 lbs./acre.

Fertilizer Needs and Application Methods

The peanut is not really a nut but a legume. If the proper strain of Rhizobia bacteria is present, they usually don't require direct applications of fertilizer nitrogen. However, studies have shown that a light application of 20-30 lbs. of N per acre often pays off by giving the young plants a good start before the nitrogen fixing bacteria have begun to function. When land is to be used that has not been planted to peanuts or cowpeas for several years, the seed should be innoculated (see under soybeans). Be sure to use the appropriate innoculant. If roots of plants more than 6 or 8 weeks old are carefully removed, you should see clusters of large, fleshy, pinkish nodules, especially on the main roots; [redacted] slice a few of the nodules open. A reddish spot in the center indicates that the bacteria are fixing nitrogen. A greenish spot shows that the nodule has ceased fixing nitrogen. A great number of small, hard,, round, white nodules scattered all over the root system means that the particular Rhizobia belong to an ineffective strain of little or no value to the plant.

Peanuts have an unusual ability to utilize residual fertilizer from preceding crops and are unlikely to give profitable responses to direct applications of P and K unless these nutrients are very deficient. If a high rate of potassium is to be applied during the same year that peanuts are to be grown, it should be broadcast and plowed under several months before planting; work has shown that high levels of K in the surface few inches of soil may seriously reduce the uptake of calcium (peanuts have a very high calcium requirement). If an NP fertilizer is used at planting, it can be applied 2" below and 2" to the side of the seeds. Use a fertilizer with a high ratio of P_2O_5 to N such as 18-46-0 or 11-48-0 since no more than 20-30 lbs. of N per acre should be applied to avoid depressing nitrogen fixation by the Rhizobia.

Peanuts grow best within a pH range of 5.5-6.5. Higher pH's will increase the likelihood of manganese deficiencies; on the other hand, very acid conditions may cause manganese and aluminum toxicities and magnesium deficiencies. Dolomitic limestone (contains magnesium) should be used for liming.

Peanuts are one of the few crops that have a high requirement for calcium as a nutrient. Light green plants plus a high % of unfilled shells may indicate lack of calcium. Gypsum (calcium sulfate) is usually used to correct deficiencies since it's a much more soluble form of calcium than limestone or burned lime. It also has no effect on pH so there's no danger of raising the pH too high if large applications are needed. The peanuts themselves won't develop in a soil layer deficient in calcium even though enough calcium is available to the roots below. For this reason, the gypsum should be dusted in a band 15" wide directly over the plants so that it will be leached down into the fruiting zone. Rates vary from about 400-800 lbs. of gypsum per acre. The gypsum also supplys sulfur which may become deficient unless some sulfur bearing fertilizer is used.

Peanuts are rather susceptible to manganese deficiencies which are most likely to occur above a pH of 6.5. The leaves become chlorotic (light yellow), but the veins remain somewhat green. Deficiencies can be corrected by spraying the plants with 5-10 lbs. of manganese sulfate per acre. "Hunger signs" for manganese in peanuts can be confused with those of sulfur and nitrogen, although the entire leaf (including the veins) becomes pale green to yellow in the case of an S or N deficiency.

CASSAVA (YUCA)

Cassava (yuca, manioc) is a drought resistant tuber crop. The tubers are ready for harvest 9-12 months after planting and may yield 2-4 tons per acre on poor soils or up to 16-20 tons per acre on deep, fertile soils. The tubers are very low in protein and vitamins but a good source of energy due to their high starch content. The tubers contain varying amounts of poisonous hydrocyanic acid (HCN), and cassava varieties can be divided into "bitter" (high in HCN) and "sweet" (lower in HCN). Even the "sweet" varieties have to 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 are better yielders.

Being a starch crop, cassava has a very high potassium requirement, and even soils high in K may become deficient after several years of continuous cassava production. Excessive rates of nitrogen will encourage above ground vegetative growth at the expense of tuber formation, and this is accentuated if K is deficient at the same time. An $N:P_2O_5:K_2O$ ratio of 1:1:2 for the fertilizer is a good general guide, but this will vary somewhat with the K status of the soil. Average fertilizer recommendations from many countries fall in the range of 40-80 lbs. N, 40-60 lbs. P_2O_5, and 80-150 lbs. K_2O per acre. The fertilizer can be placed in a semicircle around each "seed" piece about 3-4" away and 3-4" deep (portions of cut stalk are used for planting). About 1/3-1/2 of the N may be applied as one or two side-dressings later on.

SWEETPOTATOES

Unlike potatoes, sweet potatoes are a warm season crop. The starchy roots are ready for harvest in 4-6 months depending on the climate and variety.

Like other starchy crops, sweet potatoes have a high potassium requirement. Excessive amounts of nitrogen stimulate vine growth but depress root growth, and rates of more than 50-60 lbs. N per acre are seldom recommended. Most fertilizer recommendations for sweet potatoes fall in the range of 40-60 lbs. N, 40-50 lbs. P_2O_5, and 80-120 lbs. K_2O per acre, but much lower rates of K may suffice on soils high in this nutrient. The fertilizer should be applied at the time of planting and placed in a band 4" to the side and 3" deep. Sweet potatoes grow best within a pH range of about 5.0-6.5.

POTATOES

Potatoes are a cool weather crop, and profitable production in the tropics usually isn't possible at elevations much below 2000 ft. The best yields are produced where the mean temperature during the growing season (average of daily high and low) doesn't exceed 70°F. Higher mean temperatures depress tuber growth since the plants respire (burn up) much of the carbohydrate they produce instead of storing it in the tubers. Yields of up to 25-30 tons per acre are possible under top management and ideal weather, but most campesino yields run around 4-6 tons per acre.

Fertilizer Needs and Application Methods

Potatoes grow best within a pH range of about 5.0-6.5 and are fairly tolerant of acidity. Maintaining a pH of 5.5 or slightly below is an effective way of controlling potato scab where this disease is a problem.

Potatoes respond well to fertilizers due to their shallow and limited root systems and potentially high yields. Rates of up to 120 lbs. or more of nitrogen per acre may be profitable when improved varieties are used in combination with good insect, disease, and weed control. Rates from 40-80 lbs. per acre would probably give best results under campesino conditions. Except on coarse textured soils under high rainfall, there's usually little difference between applying all the N at planting time and splitting the applications. About 1/3-1/2 of the total nitrogen can be applied as a side-dressing at hilling up time.

Phosphorus is important in potato production and rates as high as 100-200 lbs. P_2O_5 are used on soils with a high capacity to tie-up P. Potatoes have a very high potassium requirement, and even soils very high in available K may become exhausted after a number of years of potato growing. Rates for soils medium in K range from 50-100 lbs. K_2O per acre; as much as 200 lbs. K_2O per acre may be applied on soils very low in K, but this would only be profitable under top management and growing conditions. When high rates of K are applied, the potassium sulfate form of K should be used instead of potassium chloride since excess chloride lowers the quality and starch content of the tubers.

In short, either all or part of the N along with all of the P and K should be applied at planting time. The fertilizer should be placed 2-3" to one or both sides of the seed pieces and slightly below their level. In very coarse textured soils, it may be advisable to split the potassium applications.

In the Highlands of Guatemala, a 90-70-40 treatment (lbs. of N, P_2O_5, and K_2O per acre) increased potato yields from an original 1¼ tons/acre to 4 tons/acre (average of 17 demonstrations conducted by the F.A.O.). Despite the low yields the treatment returned an average of $8.80 per dollar spent on fertilizer. In 22 similar demonstrations in Ecuador, a 45-45-45 treatment increased yields by an average of 36% and each dollar spent on fertilizer brought back $6.30. Be sure to soil test to get a general idea of what's needed. Combining fertilizer use with other improved practices such use of good varieties plus insect and disease control will give far better results than just fertilizer alone.

VEGETABLES

Vegetables usually give very good responses to fertilizers. High rates are often profitable, since vegetables are high value crops. Fertilizer needs are increased by the fact that most vegetables return little or no crop residues to the soil. This also means that under continuous production, large applications of composts or farm manure will be needed to maintain a satisfactory level of soil organic matter (see pp. 31-34).

Successful vegetable production requires a lot more than just fertilizer use. Selection of adapted vegetables and varieties, proper seedbed preparation, plus control of insects, diseases, and weeds are just as important. The 2 references below would be very helpful:

1. "Vegetable Gardening in the Caribbean Area", U.S. Dept. of Agric.—Agric. Research Service, Agric. Handbook #323, 1967, 65¢. An excellent practical guide for home vegetable gardening.

2. Handbook of Tropical and Sub-tropical Horticulture, U.S.A.I.D., 1964. Contains useful recommendations on varieties and on insect and disease control.

General Fertilizer Needs

The amount and type of fertilizer needed varies greatly with the soil and vegetable. The table below shows the common ranges in the amount of N, P_2O_5, and K_2O recommended per acre for various vegetables:

	N (per acre)	P_2O_5 (per acre)	K_2O (per acre)
Beans	30-60 lbs.	25-50 lbs.	20-65 lbs.
Tomatoes	60-120	40-150	75-150
Peppers	60-80	40-150	75-150
Eggplant	60-120	40-150	75-150
Cucumber	60-120	40-150	75-150
Beets	40-100 lbs.	40-120 lbs.	30-120 lbs.
Carrots	40-100	40-120	30-120
Radishes	40-75	40-100	20-100
Turnips	40-100	40-120	30-120
Onions	75-100	40-100	20-100
Lettuce	60-120	40-100	20-100
Cabbage	60-120	40-100	20-120
Cauliflower	60-120	40-100	20-120

Soils testing is a must if vegetables are being grown commercially. Field trials are also very helpful, especially as a means of diagnosing micronutrient deficiencies.

A number of vegetables are particularly susceptible to deficiencies of secondary nutrients and several micronutrients:

Calcium: Tomato, celery

Magnesium: Cabbage, cucumber, eggplant, pepper, tomato watermelon

Sulfur: The Crucifer family (cabbage, turnips, radishes, cauliflower, mustard, collards, broccoli, brussels sprouts, kale, kohlrabi), plus onions and asparagus.

Molybdenum: Cruciferae family (see under sulfur), especially cauliflower.

Boron: Cruciferae family, carrots, celery, tomatoes

Zinc: Beans, lima beans, corn

Manganese: Tomatoes, beans, lettuce, onion, radish, spinach

With the exception of molybdenum, micronutrient deficiencies are most likely to occur at soil pH's above 6.5. Molybdenum deficiencies are usually confined to very acid soils and can often be corrected by liming to pH 6.5. Borom deficiencies can be treated by applying household borax at 1 tablespoonful per 100 sq. ft. on sandy soils and up to 3 tablespoonfuls on clayey soils. This small amount can be more evenly spread if it is first mixed with sand or fertilizers to be broadcast. Overdosage can seriously injure some plants like beans. Molybdenum deficiencies can be corrected by applying 1/2 teaspoonful of sodium molybdate per 100 sq. feet. Zinc and manganese deficiencies can be treated by spraying the plants with a 1-2% solution of zinc sulfate or manganese sulfate (about 1.25-2.5 ounces per gal. of water). Copper deficiencies can be overcome by applying $1\frac{1}{2}$-2 teaspoonfuls of copper sulfate per 100 sq. ft. of soil. A 1-2% spray of ferrous sulfate ($1\frac{1}{4}$-$2\frac{1}{2}$ oz./gal.) will cure an iron deficiency.

If commercial vegetable production is important in your area, it would be well worth obtaining a copy of *Hunger Signs in Crops* (see page 48) for use in diagnosing nutrient deficiencies.

In the small garden, manure and composts can supply a good part of the nutrients needed by vegetables if applied at the rate of 75-150 lbs. per 100 sq. ft. (No more than 20-25 lbs. of sheep or poultry manure should be used per 100 sq. ft. to avoid burning).

Most vegetables grow best within a pH range of 5.5-7.5. Sweetpotatoes, potatoes, & watermelons will usually grow well down to pH 5.0. if no nutrients are lacking. Dolomitic limestone should be used if liming is needed. See pH table on [redacted] p. 95.

APPLICATION METHODS

Direct Seeded Vegetables

For direct seeded vegetables (i.e. not transplanted) which are seeded close together like radishes, carrots, beets, turnips, and beans, the fertilizer can be placed in a single continuous band 2" below and 2" to the side of the seeds. There's usually no advantage to putting bands on both sides of the seeds. Except for radishes, all the P and K plus about 1/2 of the N is applied at planting time followed by the rest of the N as a side-dressing about 6 weeks later. In the case of radishes, all the N should be applied at planting time since they mature in about 3-5 weeks.

Rates for the Small Garden: As a very rough guide, one medium handful of a fertilizer like 14-14-14 or 12-24-12 can be applied per 4 ft. of row. About 1½ cups of ammonium sulfate per 100 ft. of row can be used for side-dressing (this is equivalent to about 3/4 cup of urea). If fertilizer recommendations are available in lbs. or kgs. per acre, manzana or hectate, use the table on p. 62 to find out how much fertilizer should be applied per 25 ft. of row.

Transplanted Vegetables

Tomatoes, peppers, eggplant, cabbage, lettuce, and onions will often do better if started out in a seedbox or small, outdoor deedbed and then transplanted to the field 3-5 weeks later. This method is frequently used since it's often difficult to obtain a good stand by seeding these vegetables directly in the field due to torrential rains, un-uniform irrigation, etc.

Fertilizer may not be needed before transplanting if the soil mixture contains a good amount of compost or well rotted farm manure. (Don't use sheep or poultry manure in the seedbox or burning may result). Some authorities recommend sprinkling the young seedling once a week with a solution of 1 tablespoon of a fertilizer high in P such as 12-24-12 dissolved in 1 gallon of water once the plants reach the 2 leaf stage. If burning symptoms appear, a heavy watering will leach the fertilizer salts away from the roots and wash them off the leaves.

The use of a "starter solution" at transplanting time will help the plants recover from transplanting and get off to a good start. The solution can be made by dissolving 2-4 lbs.

of a fertilizer high in P like 12-24-12 or 10-30-10 in 50 gallons of water. Heating the water will help dissolve the fertilizer. About 1 cup of the solution should be poured in each of the transplant holes.

In addition to the starter solution, an NP or NPK fertilizer should be also applied followed by later side-dressings with nitrogen. Application methods and rates are discussed below:

TOMATOES

About 1/2 of the N plus all the P and K should be applied at transplanting time. The rest of the N should be applied as two side-dressings when the first fruit cluster has set and then 3 weeks later.

Rates for small gardens: At transplanting time, apply 1-2 tablespoons of 10-30-10 or 12-24-12 in two 1/8th circle bands about 3" deep and 3-4" from the plant. About 1-2 teaspoons of ammonium sulfate (21% N) or equivalent can be used for side-dressing and placed in a partial circle about 8" from the plant and 1" deep. Excessive N can cause delayed fruit set, and ripening as well as a high amount of fruit rotting.

PEPPERS

Follow the same program as with tomatoes.

CABBAGE AND LETTUCE

An NP or NPK fertilizer should be applied at transplanting time to furnish all the P and K plus 1/2 of the N. The rest of the N is applied when the heads begin to form. The initial fertilizer can be applied in a band 3" from the plants and 3" deep. The nitrogen side-dressing can be applied in a line about 6" from the plants and 1" deep. In the case of direct seeded leaf lettuce, the NP or NPK fertilizer should be applied in a band 2" below and 2" to the side of the seeds

Rates for small gardens: Use about 1 tablespoon of 15-15-15 or 12-24-12 per plant. One tablespoon of ammonium sulfate or equivalent per plant should be used for side-dressing.

CUCUMBERS, WATERMELONS, MELONS, AND SQUASH

These vegetables are all direct seeded in the field but are usually spaced too far apart for fertilizer to be placed in a continuous band. An NP or NPK fertilizer can be applied at planting time in a partial circle about 3-4" from each group of seeds and 3-4" deep. About 1/2 of the N is applied at planting time and the rest is side-dressed at first bloom.

All 4 plants give very good responses to farm manure; 2-3 shovelfuls of well rotted farm manure can be applied per "hill" by placing them in a hole 2 ft. wide and 1 ft. deep and covering with topsoil in which the seeds can be planted. Don't use swine or poultry manure since they may cause burning.

PASTURES

During the wet season, well managed tropical pastures can provide sufficient nutrients for normal growth of calves and beef cattle, and for the production of 1-2 gallons (10-20 lbs.) of milk daily per cow. Supplemental feeding with high energy concentrates such as corn, molasses, or sweetpotatoes, etc. will be needed for higher milk production or more rapid fattening. From one to two 1000 lb. cattle or 1½-3 600 lb. cattle for beef can be carried per acre during the wet season (or about the same number of dairy cattle). However, once the dry season sets in, both the amount and nutritive value of the herbage 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.

FERTILIZER NEEDS

Tropical grasses such as Elephant (Napier), Guinea, Pangola, Bermuda, Jaragua, and Para give excellent responses to fertilizer, especially nitrogen. Soil testing should be used to get a general idea of what's needed.

Nitrogen

Nitrogen is the most important nutrient in terms of quantity, and rates of up to 300 lbs. or more per acre yearly may be profitable under good management and year around production. Aside from increasing the yield of forage, N will also increase the protein content to varying degrees depending on the amount applied, the type of grass, and the stage of maturity at which it is grazed.

Nitrogen should be applied in several applications to reduce leaching losses. In humid areas without a pronounced dry season it's commonly recommended that N be applied 4-6 times a year. In areas with a dry season, 2-4 applications should be made, all of them during the wet season, since there's usually not enough moisture available during the dry season for fertilizers to be effective (except under irrigation). Work in Puerto Rico has shown that applying 100 lbs. of N per 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. (Grazing should be deferred following the N application until the dry seasom starts if this method is used). Guinea grass produces an especially good standing hay with this method.

If urea is used, a good deal of N (up to 25-30%) may be lost to the atmosphere as ammonia gas following broadcast applications on pastures (see p. 38). However, urea's typically lower price per lb. of N compared to other N sources and its wider availability may more than compensate for this disadvantage.

Phosphorus

Phosphorus can be applied once a year since it won't leach except in very sandy soils. Rates from 50-75 lbs. per acre of P_2O_5 are common.

Potassium

Many Central American soils have fairly high levels of available K, but have the soil tested to make sure. Up to 200 lbs. of K_2O per acre are applied on soils very low in K 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 reduce this "luxury consumption".

Sulfur

A sulfur bearing fertilizer should be included in the fertilizer program, especially for sandy soils under high rainfall. Ammonium sulfate, single superphosphate, potassium sulfate, and a number of mixed fertilizers are good sulfur sources. It's a good idea to apply around 20 lbs. of sulfur per acre yearly (60 lbs. sulfate or $SO_4^=$) using the above fertilizers.

Calcium and Magnesium

Remember that ammonium or urea fertilizers have an acid effect on the soil (see pages 41-42). Chances are that lime will eventually have to be applied after several yeats of fertilizer use or may be needed to begin with if the soil is already below pH 5.5. (Lime can be broadcast over the pasture). Soils with a low exchange capacity (see page 21) will drop in pH more rapidly than those with higher exchange capacities.

Use dolomitic limestone or else supply magnesium in another form to avoid deficiencies; cattle are very susceptible to magnesium deficiencies in pastures brought about by an excessive ratio of calcium to magnesium or by the use of high rates of potassium without supplemental magnesium. 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.

Micronutrients

Micronutrient deficiencies are unlikely except in very leached (acid) sandy soils or those much above a pH of 7.0. Molybdenum, whose availability decreases with increasing acidity, is unlikely to be deficient except in the case of legumes (kudzu, centrosema, etc.). Any more than a low concentration of molybdenum in forages is very toxic to livestock since it interferes with the animals' utilization of copper.

Value of "Self-fertilization" of Pastures by Cattle

Roughly 80% of the N, P, K, and other nutrients in the feed are returned in the manure (urine and feces), which would seem to make fertilizer use almost unnecessary after an initial application. However, animals do a very poor 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 nitrogen in the manure is lost by leaching.

What about Grass-Legumes Pastures in the Tropics?

Unlike most temperate zone pastures, few tropical pastures contain legumes. Legumes can significantly improve the nutritive value of a pasture since they have a higher protein content than grasses and will also supply the nitrogen needs of the grasses with which they are grown in combination.

Unfortunately, temperate zone legumes aren't adapted to the true tropics, and relatively little research has been done with tropical pasture legumes. Another problem is that many tropical legumes can't compete with the rapid growth made by most tropical grasses and are often shaded out. Others are sensitive to overgrazing or aren't very palatable. However, kudzu (*Pueraria phaseoloides*) and centro (*Centrosema pubescens*) have been grown successfully in combination with several tropical grasses such as Guinea, molassesgrass, and stargrass. Townsville Lucerne (*Stylosanthes humilis*) is a self-regenerating annual (it reseeds itself) that can be easily established and maintained with a variety of tropical grazing grasses. Consult a pasture specialist for recommended grass-legume mixtures for your area.

Fertilizing Grass-Legume Pastures: Since the legume can provide its own nitrogen and enough for the grass as well, nitrogen fertilizer is not needed. In fact, if N fertilizer were added, it will stimulate the growth of the grass only, and the legume will be shaded out. However, adequate potassium and phosphorus as well as sulfur are needed to maintain a good proportion of legume to grass. Compared with grasses, legumes are weak potassium extractors which stresses the importance of adding fertilizer potassium. Legumes are susceptible to molybdenum and boron deficiencies (see page 83).

USE THE "PACKAGE" APPROACH!

It takes a lot more than just fertilizer for successful beef and milk production. Good grazing management, good stock, disease control, weed control, and supplementary dry season feeding are also just as important. Some of these are touched on below:

Rotation Grazing

All grasses rapidly drop in nutritive value as they become more mature, and this is especially serious in the tropics where high temperatures encourage rapid growth. Under such conditions, some form of "rotation" grazing is just about essential to assure that the cattle "harvest" the grass before it becomes too low in nutritive value. For example, a study in Trinidad showed that the protein content of Pangola grass dropped from 15% 10 days after grazing down to 4.8% 42 days after grazing (on a dry weight basis).

Rotation grazing involves dividing the pasture up into 4-6 paddocks and putting all the cattle in one paddock at a time. The size of each paddock should be such that the cattle can 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 cool 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". Nitrogen fertilizer can be applied after each grazing. Overgrazing will use up the food stored in the roots and weaken the stand.

Silage or Hay for Dry Season Feeding

Forage quantity and quality decline drastically during the dry season. Cattle often lose a good part of their wet season gains during the dry season and may take 4-6 years to reach slaughter weight (800-1200 lbs.); this could easily be reduced to 2-3 years partly through the use of silage or hay for dry season supplementary feeding. As it is now, most campesinos have too few cattle per acre or manzana to utilize all the wet season forage production but too many cattle in terms of the scant amount of pasture available during the dry season. Making hay or silage out of the surplus wet season growth would permit much better utilization of the forage. Silage making is probably much more feasible than hay making since it would be just about impossible to dry the cut grass dowm to a sufficiently low moisture content for safe storage. (About 2 tons of water must be evaporated from fresh cut grass to produce one ton of hay). The references listed on page 86 contain helpful information on silage and hay making.

Control Weeds

Weeds rob space, water, light, and nutrients from the pasture, and some may be poisonous as well. Broadleaf weeds are the most common type; 2,4-D gives good control of non-woody broadleafs while 2,4,5-T is better for woody species. The best time for application is at the start of the rains. It's not necessary to remove livestock during or after application except in the case of dairy cows. They should stay off the pasture for a week after spraying to avoid residues in the milk.

Provide Minerals for Cattle

Except for salt, cobalt, iodime, and copper, livestock can usually obtain all their essential minerals from well managed and fertilized pastures. Salt licks containing trace minerals should be supplied to cattle. Young cattle need about 20 grams (about 2/3 oz.) of salt daily. Older cattle need about 30 grams (about an ounce). Adding one ounce of copper sulfate and 1 oz. of cobalt sulfate per 100 lbs. of iodized salt will provide a satisfactory mineral mix.

Use Stilbestrol Implants for Steers and Male Calves

Stilbestrol is a female hormone that often increases weight gains and feed efficiency in male cattle and sheep. It is usually given in the form of a pellet which is implanted under the skin of the ear but can also be administered through the feed. A single 12 milligram implant is adequate for yearling steers and its effect will last 4-6 months. In one study in Hawaii, a 12 mg. implant increased the average daily gain of steers on pasture from .95 lbs. (no stilbestrol) to 1.3 lbs. (with stilbestrol). Young male calves can be implanted at 2-4 weeks of age with one 12 mg. implant followed by a second implant at 6½ months. Two and three year old cattle should receive one 24 mg. implant which should be effective for 9 months. In studies conducted in Brazil, net returns on stilbestrol ranged from 80¢ per animal on poor dry season pasture to $6.90 on good quality wet season pasture.

Keep Animals Healthy

Cattle should be vaccinated against brucellosis at 6 months of age. Yearly vaccinations against black leg ("pierna negra") and anthrax are also recommended. Periodic worming is essential. Phenothiazine at 12 grams per 100 lbs. of body weight up to 60 grams should be given and repeated 3 weeks later. Other products are also available.

Try to obtain 2 or 3 of the references listed below which contain much helpful information of animal and pasture management:

1. "The Intensive Management of Tropical Forages in Puerto Rico", Bul. 187, Univ. of P.R. Agric. Expt. Station, Rio Piedras, P.R., published in 1964. A Spanish edition is also available.

2. The Stockman's Handbook, by M.E. Ensminger, 3rd. ed., 1962, the Interstate Printers and Publishers, Inc., Danville, Illinois. One of the best practical guides to livetsock and pasture management, covering just about everything; written mainly for temperate zone conditions, but much of the informations is relevant to the tropics.

3. An Introduction to Animal Husbandry in the Tropics, by G. Williamson and W. Payne, 2nd. ed., 1965, Longmans Ltd., London. $10.50

4. Feeds and Feeding, by F.B. Morrison, F.B. Morrison Pub. Co., Clinton, Iowa; new 23rd edition will be out in LATEr 1969. The best reference on feeds and feeding available. About $15.

5. Beef Cattle Science, 4th ed., 1968, by M.E. Ensminger, Interstate Printers and Publishers, Inc., Danville, Illinois, $14.35. A must if you're serious about working with beef cattle.

6. Grasses in Agriculture, Food and Agric. Organization, Agric. Study #42, 1959, $4.00. Available from National Agency for Internat. Publications, 317 E. 34 St., New York, New York 10016.

7. Animal Health Handbook, Chas. Pfizer & Co., 235 E. 42nd St., New York, N.Y. 10017, $1.00.

8. Merck Veterinary Manual, Merck & Co., Rahway, New Jersey. Very complete manual on livestock diseases; rather technical.

COFFEE

Of the four economically important species of coffee (arabica, robusta, liberica, and excelsa), the higher quality arabica coffee accounts for about 85-90% of the world's production and is virtually the only type grown in Latin America. Arabica coffee 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 significantly depress growth and yields. The optimum temperatures for arabica coffee are usually found from about 3500-5500 ft. in the tropics or at lower elevations in the sub-tropics. The lower quality robusta, liberica, and excelsa species require higher temperatures and are grown at low elevations in the tropics.

Coffee can be grown with or without shade but the former method is more common. Shade trees protect against excessive sunlight, reduce erosion, provide large amounts of organic matter through leaf fall, suppress weed growth, and recycle leached nutrients in the deep subsoil back to the topsoil again through the leaves. Work over the past few years has shown that unshaded coffee will often greatly outyield shaded coffee but only under the conditions of favorable climate, deep soils with good tilth, careful fertilization, and other good management practices.

Yields are generally much lower than they should be throughout Latin America, especially in the case of campesino grown coffee. Average yields in Costa Rica are around 400-500 lbs. per acre (this includes the big coffee fincas), but yields as high as 1800-2700 lbs. per acre have been obtained in experiments combining good management practices (i.e. insect and disease control, fertilizer, proper pruning, good stock, etc.).

Feasibility of Fertilizers

Much campesino grown coffee is too old and poorly managed to respond well to fertilizer. Even well managed coffee tends to give erratic responses and often takes 2-3 years to show the results of a fertilizer application since berries are only produced on two year old wood. Deficiencies of secondary and micronutrients can prevent responses from an N-P-K fertilizer treatment.

Fertilizer Needs

Although the berries themselves remove a relatively small amount of nutrients (especially if the pulp is returned to the field), fertilizer requirements are high due to the need for good vegetative growth. Nitrogen and phosphorus are the two most important nutrients 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, and you should be able to obtain specific fertilizer recommendations through the Ministry of Agriculture.

An excellent pamphlet entitled "Algunas Deficiencias Minerales Comunes en el Cafeto" by L.E. Muller contains written descriptions and color photos of "hunger signs" in coffee. It can be obtained by writing the Instituto Interamericano de Ciencias Agricolas in Turrialba, Costa Rica.

Some general information on nutrient needs is given below:

Nitrogen: Application rates range from about 60-120 lbs. of N per acre yearly. The first application is made at the start of the rains with the rest being applied later on in the wet season. Excessive nitrogen will promote leaf growth at the expense of flower formation.

Phosphorus: Young trees have a relatively higher P requirement than trees in full production. Rates for trees 1-5 years old range from about 30-60 lbs. P_2O_5 per acre yearly. Trees 5-15 years old ordinarily receive from about 25-60 lbs., and those over 15 years about 20-35 lbs. Applying P to the soil surface in a broad band under the leaf canopy gives good results; the fertilizer can be worked in slightly if there is danger of it washing away.. Coffee has a large proportion of its roots near the surface.

Potassium: Producing trees have a much higher K requirement than young trees. Rates of 20-40 lbs. K_2O per acre yearly are commonly applied to young trees and up to 60-120 lbs. on older trees unless the soil is already high in K. All the K may be applied once a year, but it is often applied in 2 applications.

Calcium and Magnesium: Coffee often grows well down to a pH of 5.0 or slightly below if sufficient calcium is available, although a pH of 6.0-6.5 is said to give best results in many cases. Higher pH's increase the likelihood of micronutrient deficiencies (except molybdenum). Coffee has a relatively high calcium requirement. Magnesium deficiencies are apt to occur in very acid soils and are also caused by a high ratio of potassium to Mg. Soil applications of dolomitic limestone or magnesium sulfate are commonly used to maintain a satisfactory Mg level or to treat deficiencies. However, it often takes 15-18 months for soil applications of Mg to eliminate deficiency symptoms, and more rapid results can be obtained by spraying the trees 3-7 times at two week intervals with a 1-2% solution of magnesium sulfate (epsom salts).

Micronutrients: Coffee is sensitive to micronutrient deficiencies, especially zinc, boron, iron, and manganese. Foliar sprays are the common treatment; a sticker-spreader should be used to assure adequate spreading and resistance to washoff. Zinc deficiency is common in Costa Rica and Brazil and can be treated by a foliar spray of 4 lbs. zinc sulfate plus 2 lbs. slaked lime (calcium hydroxide: $Ca(OH)_2$) to reduce chances of burning. One application at the start of the rains followed by another midway in the rainy season are usually sufficient. Boron deficiency is widespread in Costa Rica and can be controlled by applying 1-2 ounces of borax around each tree or by spraying with a solution of 4 lbs. borax plus 2-4 lbs. slaked lime in 100 gallons of water. Coffee is also sensitive to Boron toxicity. Iron deficiencies are most common above a pH of 6.5 but can also be caused by a relative excess of phosphorus to iron. Chelated iron formulations applied at about 15 grams per tree give good results (see page 40). Manganese deficiencies can be treated with a spray containing 4 lbs. manganese sulfate plus 2 lbs. slaked lime in 100 gallons of water. Coffee is also sensitive to manganese toxicities which are likely to occur in very acid soils. Applying 5 lb. ground limestone per tree will usually control this problem.

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profit per acre which is what he's after. He doesn't have to worry about getting a maximum return per dollar since he has enough money to fertilize all his land at the maximum profit rate. The farmer with ample capital is in the same position as the large chain store that sells its goods at a lower price than its smaller competitors but still makes more total profit due to its much larger sales volume.

On the other hand, the campesino who can afford only a limited amount of fertilizer must shoot for a maximum return per dollar spent rather than maximum profit per acre (this would be at point "A" on the graph right before diminishing returns start setting in). This means he's usually much better off fertilizing a larger area of land at low to medium rates than a smaller area of land at a higher rate. For example, in the fertilizer trial on page 87, 160 lbs. of N would produce 119 bushels of corn if applied on one acre; however, if the same amount were spread over 4 acres (i.e. 40 lbs. per acre), a total of 216 bushels would be produced. Remember that the amount of fertilizer that will produce about the maximum return per dollar depends very much on the crop, variety, soil conditions, nutrients, and crop and fertilizer prices. For instance, on the same soil the maximum return per dollar of fertilizer on a high value crop like tomatoes might occur at a higher rate than on a low value crop like corn. However, don't spread fertilizer too thin; too low a rate might only be enough to get the plants off to a good start followed by a mid-season "poop out". As a very rough guide, apply at least 30 lbs. N, 20 lbs. P_2O_5, and 20-30 lbs. K_2O per acre (chekk to see if K is needed first).

<u>Substitution of Fertilizer for Land</u>: Another point to consider is that fertilizer can substitute for land. The campesino using fertilizer will be able to produce as much corn & beans as before on considerably less land by increasing productivity per acre. He will then be able to diversify production.

II. FACTORS AFFECTING CROP RESPONSE TO FERTILIZER

1. Type of Crop

Corn, sorghum, short strawed rice varieties (see p. 66), sugar cane, bananas, pastures, and most vegetables are more likely to give good responses to fertilizer than coffee, cacao, citrus, and other tree crops, except if the latter are suffering from a severe deficiency. Soybeans and peanuts often respond better to residual fertility than to directly applied fertilizers.

2. Variety

Improved varieties and hybrids usually give a much better response to fertilizers than "criollo" (native) ones.

In a fertilizer trial in India with corn, a hybrid and a local variety were compared under the same fertilizer treatment (80 lbs. N/acre); the hybrid yielded 8000 lbs. per acre while the native variety yielded only 2000 lbs.

3. Maintaining an Adequate Nutrient Balance

If two nutrients are simultaneously deficient in a soil, the addition of one alone will often have little effect. For example, a fertilizer trial with corn on a soil where both nitrogen and phosphorus were deficient gave the following results:

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

In some cases, the relative excess of one nutrient can depress the availability or uptake of another:

1. A high ratio of potassium and/or ammonium to magnesium may cause an Mg deficiency in susceptible crops like tobacco and pastures. A HIGH RATIO OF POTASSIUM AND/OR AMMONIUM TO CALCIUM MAY CAUSE A CALCIUM DEFICIENCY IN PEANUTS.
2. Large applications of phosphorus can cause iron or zinc deficiencies in soils where they are already low in availability.
3. A high ratio of calcium to magnesium can cause Mg deficiencies.
4. Overliming the soil may cause micronutrient deficiencies (except for molybdenum).
5. Excess soluble copper and manganese can cause iron deficiencies and vice-versa.

4. Weeds

Adequate weed control is a must. Weeds compete with the crop for water, light, and nutrients. For each lb. of dry matter produced, weeds transpire 200-800 lbs. of water into the atmosphere (25-100 gallons). One review of losses caused by weeds in corn showed yield losses ranging from 41-86% when weeds weren't controlled.

5. Insect and Disease Control

Well fertilized plants are generally more disease and insect resistant, but an attack can easily wipe out profits, unless proper control measures are taken.

6. Soil Moisture

Adequate soil moisture is vital for good fertilizer response. Much lower rates have to be used in areas of sub-optimal rainfall since plants aren't able to use as much, aside from the greater danger of fertilizer burn. However, fertilizer does increase drought resistance and moisture use efficiency. On the other hand, too much moisture prevents enough oxygen from reaching the roots which prevents both water and nutrient uptake (rice is an exception).

7. Soil Characteristics

Excessively sandy or clayey soils, poor tilth (see p.10), hardpans, and very shallow soils will all lower crop response to fertilizer.

8. Time and Method of Fertilizer Application

The response you get from fertilizer depends a lot on how and when you apply it. (See pp. 54-89).

9. Plant Population and Spacing

Plant population and spacing affect fertilizer response, especially in the case of corn. Too few or too many plants per acre will limit returns. The optimum plant population per acre varies with soil fertility, available moisture, and the variety. Consult an agronomist for optimum plant populations for corn in your area. They usually range from 5000-10,000 plants per acre under low fertility and/or moisture to 14,000-18,000 per acre under good fertility and moisture. Final stands of 19,000-24,000 per acre are only recommended under top management and fertility, adequate moisture, and the use of a hybrid adapted to high populations. Replant by 15-20% to assure the final stand you're aiming for.

Plant spacing is also important. Many campesinos plant 4-7 grains of corn per hole with the holes a yard or more apart . This minimizes the labor of hand seeding since fewer holes have to be made to seed the same number of plants; however, the plants within each hole must compete for water, light, and nutrients within a limited area. A final stand of 2-3 seeds per hole is a good compromise between idea spacing and the need to minimize labor.

THE "PACKAGE" APPROACH TO IMPROVING CROP YIELDS

You'll make far greater headway in improving crop yields by introducing a "package" of improved practices rather than just fertilizer alone. In many cases, fertilizer use may not be profitable without insect and disease control and the use of an improved variety. Use of any one practice by itself is likely to give only mediocre results compared to combining several improved practices. For example, in village demonstrations in India, hybrid corn yielded 2000 lbs. per acre and native corn 1800 lbs. per acre when grown under local production practices (no fertilizer, no insect control, etc.). However, when both ware grown under improved practices, the hybrid produced 4 times the yield of the native variety.

Another example of how improved practices interact with eachother is shown by the results of an experiment conducted with wheat in Mexico:

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

The campesino is no less profit motivated than other people, and much of his supposed conservatism is really pure shrewdness. Nearly all campesinos want to increase their yields and income but will adopt new farming methods only if they promise a substantial return without excessive risk. The use of the "package" approach will greatly increase ~~your~~ chances of success.
HIS

PART VIII

LIMING SOILS

Soils are limed to correct excessive soil acidity (raise pH). Very acid soils (below pH 5.5 or so) adversely affect the growth of most crops for several reasons:

1. Aluminum and manganese become more soluble with increasing acidity and may become toxic to plants at pH's of about 5.5 or below.

2. Very acid soils are often low in available phosphorus since the ability of iron and aluminum to "tie up" P increases with acidity (see p. 26).

3. Very acid soils are likely to be low in calcium, magnesium, and available molybdenum and sulfur.

4. Excessive soil acidity depresses the activities of many beneficial soil microbes, including those that convert unavailable organic N, P, and S to available mineral forms (see p. 6). The particular strains of nitrogen bacteria associated with soybeans, alfalfa, and some clovers are similarly affected.

Most crops grow best within a pH range of 5.5-7.5, but there is some variation as shown below:

RECOMMENDED SOIL pH's FOR COMMON CROPS*3

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
Sugar cane	*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	6.0-7.5	Watermelon	5.0-7.0

*1. The above crops may grow fairly well at least one half a pH unit both above and below the optimum ranges given. An asterisk (*) before a pH range means that fairly good growth may occur one full pH unit below the range given. An asterisk after a pH range means that fairly good growth may occur one full pH unit above the range given.

*2. Use a pH of 5.5 or slightly below to control potato scab or black rot of tobacco.

*3. Table slightly modified from Efficient Use of Fertilizers F.A.O. Ag. Study #43, 1959, pp. 137-8.

TYPES OF LIMING MATERIALS

There are 4 basic types of liming materials: limestone, dolomitic limestone, burned lime (quicklime), and hydrated lime (slaked lime or calcium hydroxide).

Limestone (calcium carbonate, $CaCO_3$): the cheapest of all liming materials since it's taken directly from the ground and crushed without further processing. Non-caustic.

Dolomitic limestone ($CaCO_3 \cdot MgCO_3$): Contains both calcium and magnesium carbonates. Dolomitic limestone is often recommended, since the application of purely calcium liming materials may cause Mg deficiencies (see p. 28).

Burned lime or Quicklime (CaO):*1 Comes in the form of a white powder; very caustic. Made by heating limestone in a kiln to drive off the CO_2 to leave calcium oxide (CaO). More effective per pound than other materials (see table below) and more rapid acting. However, it tends to form granules or flakes unless thoroughly mixed with the soil.

Hydrated lime (slaked lime, calcium hydroxide):*1 Made by burning limestone in the presence of steam. Not a popular liming material 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%

For example, if burned lime has a neutralizing value of 179%, this means that 2000 lbs. of burned lime would have about the same effect as 3580 lbs. of limestone of equal purity.

QUALITY OF LIMING MATERIALS

Purity and fineness are the factors that determine the quality of a liming material.

Purity: It's hard to judge the purity of a liming material without a lab analysis unless it is stated on the label. The greater the impurities, the more material will be needed.

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*1. Both burned lime and hydrated lime are also made from dolomitic limestone.

Fineness: The rate at which a liming material will react with the soil depends a lot on its particle size. The finer the material, the more rapid the reaction. However, even fine textured materials may take 2-6 months to cause a significant rise in soil pH, Good quality burned lime and hydrated lime have a naturally fine texture, but crushed limestone is often overly coarse.

Any type of liming material will contain a mixture of different particle sizes. It's best to use only that portion that will pass through a 10 mesh screen (about 10 openings each way to the inch). Liming materials with a relatively large propoetion of coarse particles can be used, but they will take a much longer time to react with the soil.

HOW MUCH SHOULD BE APPLIED?

The amount of lime needed to obtain a certain rise in soil pH depends on soil texture plus the fineness, purity, and neutralizing value of the liming material used.

How Soil Texture Affects the Amount of Lime Needed

A lot more lime is needed on clayey soils than on sandy soils to achieve the same rise in pH. For example, a sandy soil with a pH of 4.5 might need only 1600 lbs. or so of pure limestone per acre to raise the pH to 6.0, but a clay loam might need as much as 5000-6000 lbs. to achieve the same rise in pH. That's because soils have both active and reserve acidity. The active acidity is produced by those hydrogen ions (H^+) floating around in the soil water and is what you measure when you take a soil pH reading. However, for every H^+ ion floating around free, there may be several thousand more attracted to the negatively charged clay and humus particles (see p. 20). As the lime neutralizes the H^+ ions floating around free, part of the huge reserve of H^+ ions held by the clay and humus particles is released into the soil water to take the place of thise that were neutralized. The higher the content of clay and humus in the soil, the greater the negative charge (exchange capacity) and reserve acidity, and the more lime will be needed to obtain a given rise in soil pH.

An important point is that many soils in the tropics require less lime than temperate soils of the same texture to obtain an equal rise in pH. The reason is that many soils in the tropics contain clays with a lower exchange capacity than temperate zone clays (see p. 4) and therefore have a lower reserve acidity.

The fact that fine textured soils have a higher reserve acidity than coarse textured soils doesn't mean that they are more acid in terms of pH. pH measures only the active acidity of the soil. Clayey soils can be just as acid or alkaline as sandy soils but are more resistant to pH changes due to their greater buffering ability which is caused by their higher exchange capacity.

Calculating the Amount of Lime Needed

When you measure soil pH with a pH test kit or other device, you're only measuring the active acidity. Since it's the reserve acidity that determines the amount of lime needed, a pH reading by itself won't be of much help. Most soil testing labs can determine the amount of lime your soil will need to reach a certain pH, but you'll still have to adjust their recommendations to the fineness, purity, and neutralizing value of the material being used (see pp. 93-94 76-77).

You can roughly calculate thr amount of lime needed by using the table below. Check the soil pH about 2-6 months after applying the liming material to measure the effect.

Approximate Amounts of Finely Ground Pure Limestone Needed[*1] to Raise the pH of a 7 Inch Layer of Soil as Indicated:

(For most soils of tropical and sub-tropical regions)

	Lbs. of pure limestone needed per acre to raise the pH of a soil from:	
Soil Texture	pH 4.5-5.5	pH 5.5-6.5
Sand or loamy sand	540 lbs./acre	800 lbs./acre
Sandy loam	1000 lbs.	1400 lbs.
Loam	1500 lbs.	2000 lbs.
Silt loam	2400 lbs.	2800 lbs.
Clay loam	3000 lbs.	3800 lbs.

Adjust these rates to the neutralizing value and purity of the material you're using. For example, 1000 lbs. of finely ground limestone per acre is equal to about 560 lbs. of burned lime (1000 ÷ 1.79); if the burned lime were only 80% pure, you'd need about 700 lbs. (560 ÷ .80) of it. The texture of the material will also affect the amount needed (the coarser the texture, the more needed).

HOW AND WHEN TO APPLY LIME

Lime should be broadcast uniformly over the field and then thoroughly mixed into the top 6-8" of soil by plowing or hoeing. Harrowing (disking) does a less satisfactory job since it will only move the material around in the top

*1. Based on table in Efficient Use of Fertilizers, F.A.O. Ag. Study #43, p. 140. Remember that not all soils in the tropics are really "tropical" in terms of clay type; non-tropical clays require more lime to achieve the same rise in pH. See pp. 4 & 18 in the manual.

2-3" of soil. Where more than 3-6 tons of lime per acre are to be applied at once, half the amount should be applied before plowing (disk plow or moldboard plow) and the remaining half applied after plowing but before harrowing. This method will give more thorough and uniform mixing of large amounts of lime. When applying lime to established pastures, it can be broadcast directly over the grass (no mixing is necessary, nor would it be possible without tearing up the pasture).

Apply liming materials 2-6 months before planting time, since it will take at least this long for soil pH to be affected. This is especially important with the caustic forms of lime (burned lime and slaked lime) to prevent injury to plants.

Liming may be needed every 3-5 years on some soils, especially if high rates of acid forming fertilizers are used (see pp. 41-42). Coarser textured soils will require liming more frequently than finer textured soils.

DON'T OVERLIME!

Never raise the pH of a soil above 6.5 by liming. Always raise the pH by no more than one pH unit at a time. It may only be necessary to raise the pH to 5.5 or 6.0 for best yields with many crops. Crops grown on soils whose clay fraction is dominated by "tropical" clays (see p. 4) are generally more tolerant of low soil pH's than when grown on other types of soils.

OVERLIMING CAN BE WORSE THAN NOT LIMING AT ALL:

1. Raising the pH above 6.5 by liming increases the likelihood of micronutrient deficiencies (except those of molybdenum).

2. The availability of phosphorus begins to decrease above pH 6.5 due to the formation of relatively insoluble compounds with calcium.

3. Liming stimulates the activity of soil microbes, and overliming may cause excessive losses of organic matter through increased decomposition.

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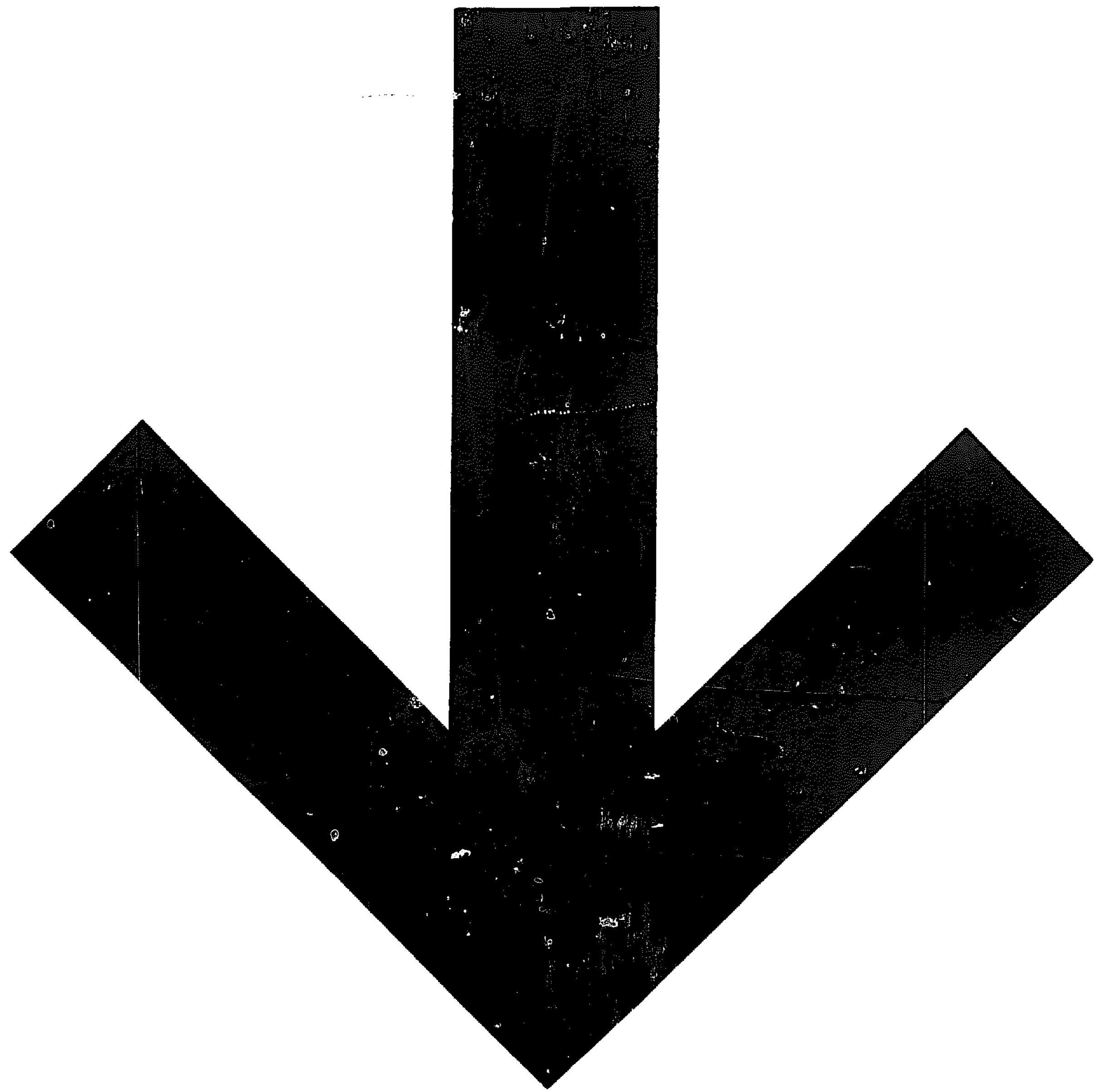

INDEX

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