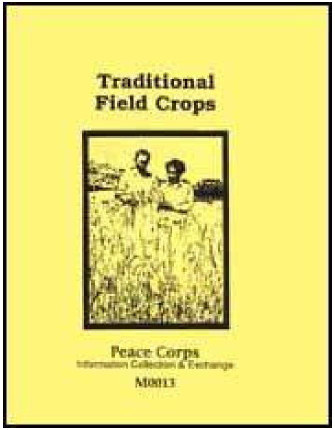


# Traditional Field Crops (Peace Corps, 1981, 283 p.)

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## GIossary

| | |
|---|---|
| Crop rotation: | The repetitive growing of an orderly succession of crops on the same field. |
| Field trial: | An on-farm trial repeated simultaneously on a number of local farms to compare a new practice or "package" of practices with the present practice or practices. It is designed to obtain information, not as a demonstration. |
| Fungicide: | Any pesticide that kills or halts the development of fungi. |
| Herbicide: | Any pesticide that kills weeds. |
| Hybrid: | A type of improved crop variety produced by crossing two or more inbred lines of a crop. |
| Legume: | Any plant belonging to the Leguminosae Family whose members all produce their seeds in pods. Legumes can satisfy part or all of their nitrogen needs through a symbiotic relationship with Rhizobia bacteria that form nodules on the roots. Beans, cowpeas soybeans, |

| | |
|---|---|
| | mungbeans, lima beans, chickpeas, pigeonpeas, and peas are legumes. |
| Monoculture: | The repetitive growing of a single crop on the same field year after year. |
| Multiple cropping: | The growing of two or more different crops at the same time on the same field: also referred to as intercropping. |
| Nematodes: | Tiny, colorless, threadlike roundworms that live in the soil and parasitize plant roots. |
| Nitrogen fixation: | The beneficial process by which Rhizobia bacteria convert atmospheric nitrogen into a usable form for plants. Rhizobia bacteria are associated only with legumes. |
| Phosphorus fixation: | The process by which added fertilizer phosphorus becomes tied-up as insoluble compounds in the soil and unavailable to plants. Phosphorus fixation is a problem on all soils but is especially severe on highly weathered, acid, red tropical soils. |
| Pulse: | A legume crop whose mature dry seeds are suitable for human consumption; examples are beans, cowpeas, soybeans, chickpeas, and mungbeans. |

| | |
|---|---|
| Result test: | See field trial. |
| Rhizobia: | A type of bacteria associated with legumes and capable of nitrogen fixation. |
| Soil texture: | The relative amount of sand, silt, and clay in a given soil. |
| Soil filth: | The current physical condition of a soil in terms of its workability and ease of moisture absorption. A soil's filth can vary markedly with its texture, humus content, and current moisture content. |
| Systemic insecticide: | An insecticide that is absorbed into the plant sap and translocated (transported) throughout the plant. |
| Threshing: | The process of separating the seeds of cereal and pulse crops from the seedheads, cobs or pods. |
| Tillering: | The production of sideshoots by a crop during its growth; tillering is common in millet and sorghum. |
| Transpiration: | The loss of soil moisture by plant root absorption and passage into the air through the leaf pores. |
| Winnowing: | The process of separating chaff and other light trash from threshed grain using wind, fandriven air or screens. |

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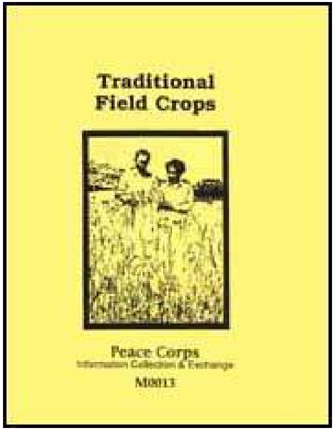


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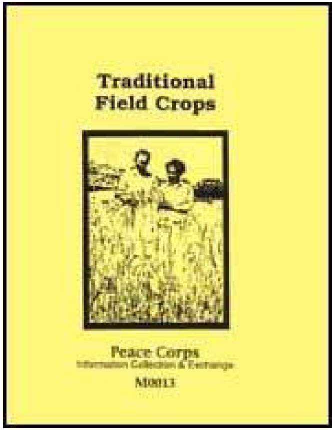


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**Pradesh 502 324, INDIA**

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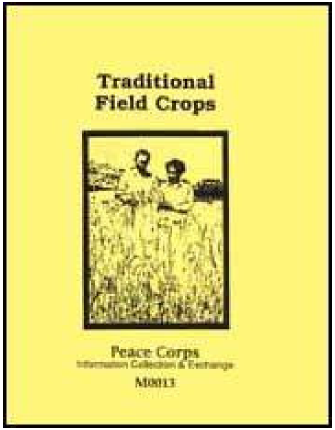


# Traditional Field Crops (Peace Corps, 1981, 283 p.)

## About this manual

**The Traditional Field Crops manual is designed as a learning tool and on-the-job reference for Peace Corps Volunteers involved in small farmer crop improvement programs in maize, sorghum, millet, peanuts, beans and cowpeas. Although written to be readily understood by nonspecialists, the manual contains much information useful to trained agriculturalists and to planners and trainers. Primarily designed to help Volunteers develop and strengthen the agricultural skills they need for successful work with the target crops, this manual focuses on the following areas:**

- **Surveying and interpreting the local agricultural environment and individual farm units**
- **Developing agricultural extension techniques and practices**
- **Providing basic "hands-on" and technical skills for extension workers in operations from farm land preparation through harvest, including some routine troubleshooting.**

**To do this, the manual provides a summary of current crop production recommendations under varying conditions of climate, soils, management ability, and available capital; identifies useful field references and other technical resources, including information on improvements in equipment for small farmer row crop production; and reviews recent research advances and extension efforts in target crop yield improvement with special emphasis on the role of international crop institutes. Scientific names are used along with common names to avoid confusion, as one common name may refer to a number of different species.**

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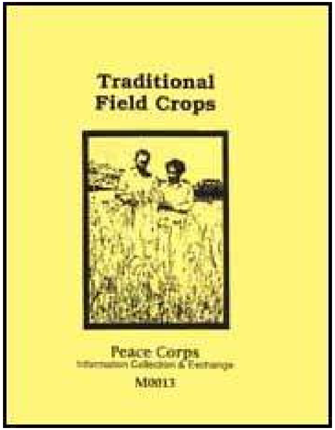




## About the author

**David Leonard has been associated with the Peace Corps off and on for the past eighteen years. Originally a B.A. generalist (history), he served as an agriculture extension Volunteer in Guatemala from 1963-65 and then went on to get a Master of**

**Agriculture degree in agronomy from Oregon State in 1967. Since then, he has been an agriculture trainer for 35 groups of Peace Corps Volunteers bound for Latin America, Africa, and Asia. He also grew maize, potatoes and peanuts for three years on a 120hectare farm in Australia.**

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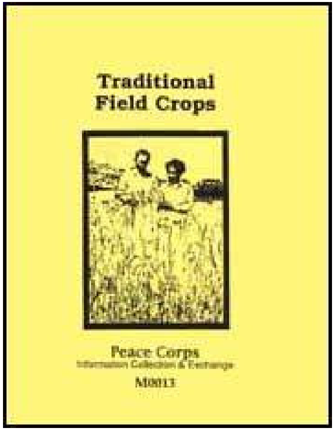

**Acknowledgments**

**I would like to express special thanks to John Guy Smith of Washington, D.C., for assistance in planning this manual and for permission to use materials from several of his publications. No one better understands the realities of small farmer agriculture and the development and introduction of improved farming practices.**

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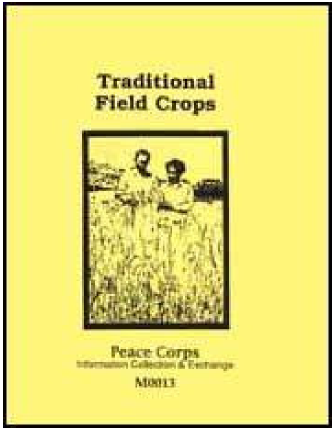




## Traditional Field Crops (Peace Corps, 1981, 283 p.)

## Introduction

**From 1961 to 1975, total food production in developing countries increased about 47 percent. This seemingly impressive gain was reduced to only 10 percent in terms of food production per person because of rapid population growth rates. In more than half of the developing nations, per person cereal grain production was less in 1979 than in 1970. Presently, some two-thirds of all people in the developing countries are considered undernourished.**

**Current world food supplies compared with dietary requirements show only a minor deficit on paper, but the reality is far more serious for two reasons:**

- **Food supplies are distributed inequitably among countries, different income groups, and even within the family. Since the quantity and quality of food intake is strongly linked to income level, increases in per person food production will have little effect on hunger and malnutrition without a large rise in the incomes of the world's poor.**

- **Postharvest food losses of cereals and legumes (dry beans, peanuts, etc.) during processing and storage are conservatively estimated to be 10 percent on a world basis, but losses of 20 percent are common in developing countries. Looking to the future, there is little reason for optimism. A 1974 UN study predicted that in the next 30 years, human population will increase by 26 percent in the developing countries, 62 percent, and 119 percent in the developing nations. The study concluded that if current food production trends continue in developing countries, they will need to increase their grain imports fivefold between 1970 and 1985. Aside from the problem of financing such imports, it is very questionable whether the major grain exporters can meet these needs.**

**It is not likely that developing countries can increase food production rapidly enough during this decade to achieve selfsufficiency. However, the food deficiency can be narrowed if these countries strengthen their recent interest in crop improvement practices and introduction of new techniques to both small- and largescale farmers.**

**The small-scale farmer and agricultural development**

**The great majority of farmers in developing countries operate on a small scale. Despite much local and regional diversity, they share a number of important characteristics:**

- **Most small farmers operate as independent economic units, either as independent proprietors or under a rental arrangement allowing them to make production decisions. In some cases, however, individual decision-making may be subject to tribal or village controls, or restricted by insecure tenancy.**

- **Since they have a small amount of land and capital, they depend mainly on the family labor supply.**

- **The small-scale farmer is less likely than large-scale farmers to use capital for commercial inputs like fertilizers, pesticides, and equipment.**

- **The small farmer tends to use credit for consumption needs rather than for purchasing farming inputs.**

- **Compared to larger farmers, small farmers have limited access to important production factors associated with agricultural development such as agricultural credit and supplies, adapted technology, technical assistance, market information, roads, and transport.**

**Assisting small farmers**

**In the developing world, most small-scale farmers with whom the extension worker is in contact are farmers in transition from traditional to improved production practices. They are aware of outside inputs like fertilizers, insecticides, and vaccines for livestock and may actually be using one or more of these, though often in a haphazard manner. Although their first production priority is usually subsistence, there is a strong motivation to produce a marketable or exchangeable surplus once the family food needs are met.**

**Much of the solution to hunger and rural poverty in the developing countries hinges on the small farmer's ability to increase his or her returns from traditional crops by adopting**

**appropriate improved production practices. "Appropriate" means in harmony with the environment and the cultural and economic situation of the farmer. "Improved" refers to the use of non-traditional inputs like fertilizers, agricultural chemicals, new equipment suited to small-scale farming, and technical advisory services. It does not imply the total abandonment of traditional growing practices but rather the incorporation of suitable new elements.**

**Most small-scale farmers will benefit by participating in agricultural development programs. Since nearly all of them want to increase their yields and incomes, they will adopt new techniques--if these offer a reasonable assurance of a meaningful return without excessive risk and the necessary inputs are available.**

**Until fairly recently, yieldimproving technology was usually developed with little regard to the realities of the small farmer's situation. It is not surprising that these so-called "improved" practices often encountered a cool response. Crop production research and extension are becoming more attuned to the small**

**farmer's needs, and there are numerous examples of successful yield-improving programs involving small farmers throughout the developing countries.**

**The Small Farm As a Viable Economic Unit**

**When yield-improving practices are used in developing countries, competitively low production costs can be realized over a wide range of farm sizes. Increasing the size of the farm alone is usually not the answer to production problems for all small farms, although it can be an important factor for some.**

**There are basically two types of small farm. One is the family-size farm, which can gainfully employ the equivalent of two to four adults and a team of oxen. This type of farm is much smaller in size and capital than its equivalent in the developed countries, probably because land and machinery are more expensive than labor in most developing countries.**

**The sub-family farm is too small to effectively employ the equivalent of two adults and a team of oxen. Unfortunately, in**

**countries like Guatemala, El Salvador and Peru, up to 80-90 percent of the total farm units are classified as subfamily. The sub-family farm is too small to become economically successful no matter how much improved technology is used. In this case, increased size is vital to production.**

**The Availability Of Improved Production Practices**

**Since the 1960s, there has been a growing effort on the part of national and international crop research organizations to develop feasible yield-improving practices for the reference crops included in this manual. This is a long, ongoing process, but for many farming regions in developing countries there is now a group of improved practices that will provide significant increases in both yields and returns over traditional methods. These developments are the small farmers' best hope for increasing yields and returns so that they can remain (or become) competitive economically and improve their standard of living. The ideal conditions for promoting improved crop production practices among small farmers would ensure that:**

**• the new practice does not increase farmer risks, depart radically from current practices, or require considerable retraining of the farmer.**

**• the potential gains exceed the added costs by at least two to one. (This is the cost/ benefit ratio.)**

**• the commercial inputs and associated services required for the practice are readily obtainable on reasonable terms.**

**• The pay-off from the new practice occurs in the same crop cycle in which it is applied.**

**• The costs of the new practice are within the farmer's means. This usually implies access to credit.**

**All of these conditions are seldom fully met in small farmer agriculture in a developing country. Nonetheless, with a good extension service and a well-developed "package of practices", agricultural extension workers can improve crop yields on small farms dramatically.**

# The ''Package'' approach to improving crop yields

**In most cases, low crop yields are caused by the simultaneous presence of several limiting factors, rather than one single obstacle. When a specially developed and adapted "package" of improved practices is applied to overcome these multiple barriers, the results are often much more impressive than those obtained from a single factor approach. A crop "package" consists of a combination of several locally proven new practices. (Few packages are readily transferable without local testing and modification.) Most include several of the following: an improved variety, fertilizer, improved control of weeds, pests, and diseases, improvements in land preparation, water management, harvesting, and storage.**

**The likelihood of a positive response is greatly increased using a package approach. However, there are possible disadvantages:**

- **If the package fails, farmers may conclude that all of the individual practices are unproductive.**

- **More adaptive research and extensive local testing are required to develop a proven package for an area.**

- **The package may favor the larger farmers who have easier access to credit for buying the added inputs.**

- **Unavailability of a component input or its faulty application may make the entire package fail.**

**It should be streseed that a package does not always have to involve considerable use of commercial inputs. In fact, an extension program can focus initially on improvement of basic management practices that require little or no investment such as weeding, land preparation, changes in plant population and spacing, seed selection, and timeliness of crop operations. This helps assure that small farmers benefit as least as much as larger ones, especially in those regions where agricultural credit is poorly developed.**

## The role of the extension worker

**To work with small farmers to improve yields of the six reference**

**crops (maize, sorghum, millet, peanuts, cowpeas, and beans), extension workers need both agricultural and extension skills. The general agricultural skills required by extension workers who will be involved in crop improvement projects as intermediaries with a limited advisory role include:**

- **understanding the need for crop improvement programs**
- **interpreting the agricultural environment**
- **knowledge of the reference crop characteristics**
- **knowledge of crop improvement practices**
- **understanding of reference crop management principles.**

**Extension workers also will need to have an appropriate level of "handson" and technical skills relevant to the reference crops, and an ability to adjust recommendations for variations in local soils, climate, management, and capital.**

**This manual provides most of the information extension workers need to work with the six reference crops. In promoting any crop improvement practice, however, it is very important to work with the local farmers, extension service, universities, and national**

**and international agricultural research institutions. These individuals and organizations are much more familiar with the prevailing local environmental, economic, social and cultural conditions and should be consulted first before attempting any crop improvement program.**

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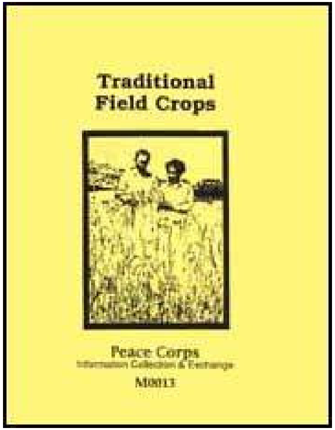


Introductory orientation

Orientation to the farm unit

**Traditional Field Crops (Peace Corps, 1981, 283 p.)**

## The agricultural environment

**The purpose of this chapter is to identify how extension workers can survey and interpret important features of the local agricultural environment and the individual farm units which are a part of it. This is vital to effective extension since it enables workers to fully comprehend the area's farming systems and practices.**

**The local agricultural environment is made of up those factors which influence an area's agriculture. The most important of these are the natural (physical) environment and the infrastructure.**

## The natural environment

**The natural environment consists of the climate and weather, the land and soils, and the ecology (the interaction among crops, weeds, insects, animals, diseases, and people).**

**Weather refers to the daily changes in temperature, rainfall, sunlight, humidity, wind and barometric pressure. Climate is the typical weather pattern for a given locality over a period of many years. To quote one definition, people build fireplaces because of the climate, and they light fires in the fireplaces because of the weather.**

**The climate and weather factors that have the greatest influence on crop production are solar radiation (sunlight and temperature), rainfall, humidity, and wind.**

## Solar Radiation

**Solar radiation markedly influences crop growth in several ways:**

- **It provides the light energy needed for photosynthesis, the fundamental process by which plants manufacture sugars for use in growth and food production. Sugars are** made by this process in the green cells of plants when carbon dioxide from the air combines with water from the soil using sunlight and chlorophyll (the green pigment in plants) as catalysts.

- The daily duration of sunlight (daylength) and its yearly variation greatly affect time of flowering and length of growing period in some crops.

- Solar radiation is the primary determinant of outside temperature, which strongly influences crop growth rate and range of adaption.

## Regional and yearly variations in solar radiation

Unlike the temperate zone latitudes, the region between the Tropic of Cancer (23.5°N) and the Tropic of Capricorn (23.5°S) has relatively little seasonal variation in solar radiation, since the sun remains fairly high in the sky all year long. Measurements above cloud level show an annual variation in solar radiation of just 13 percent at the equator versus 300 percent at a latitude of

**40°. However, this supposed advantage of the tropics may in some cases be largely offset by cloudiness, which can be excessive in the higher rainfall zones, particularly near the equator (cloudiness can reduce solar radiation by 14-80 percent depending on depth and extent of the cloud cover). For example, due to heavy cloud cover, the equatorial Amazon Basin receives only about as much total yearly solar energy at ground level as the Great Lakes region of the U.S.**

## Daylength

**The length of time from plant emergence to flowering as well as the actual date of flowering can be strongly affected by daylength in the case of some crops. Among the reference crops, soybeans and the photosensitive varieties of millet and sorghum are the most affected.**

**Maize is less influenced by daylength unless a variety is moved to a latitude where daylength is markedly different from that of its point of origin (see Chapter 3). Daylength is usually not a critical factor with peanuts, beans and cowpeas.**

**As shown by the table below, both latitude and season influence daylength. Note that the annual variation in daylength markedly decreases as the equator is approached.**

**Table 1 Length of Day in Various Northern Latitudes**

| Month | Equator | 20° | 40° |
|---|---|---|---|
| Dec. | 12:07 | 10:56 | 9:20 |
| Mar. | 12:07 | 12:00 | 11:53 |
| Jun. | 12:07 | 13:20 | 15:00 |
| Sep. | 12:07 | 12:17 | 12:31 |

**Temperature**

**Temperature is the major factor controlling a crop's growth rate and range of adaption. Each crop has its own optimum temperature for growth, plus a maximum and minimum for normal development and survival. Even varieties within a crop differ somewhat in their temperature tolerance. Excessively high daytime temperatures can adversely affect growth and yields by**

**causing pollen sterility and blossom drop. In addition, the hot nights common in the tropics can reduce crop yields. This is because plants manufacture sugars for growth and food production by the daytime process of photosynthesis, but "burn up" some of this at night through the process of**

**respiration. Since high nighttime temperatures increase the respiration rate, they can cut down on the crop's net growth. Several factors affect an area's temperature pattern:**

- **Latitude--Seasonal temperature variations are pronounced in the temperate zone where solar radiation and daylength fluctuate considerably over the year. In the tropics, this seasonal temperature difference is much smaller. Nighttime lows are seldom below 10-30°C near sea level and are usually above 18°C. Seasonal variations become more pronounced as the distance from the equator increases.**

- **Elevation--Temperature drops about 0.65°C for each 100meter rise in elevation. This greatly affects a crop's**

**length of growing period as well as its adaptation to the area. For example, at sea level in Guatemala, maize matures in three to four months and the climate is too hot for potatoes; however, about 50 km away in the highlands (above 1500 m), maize takes five to ten months to mature and potatoes thrive.**

- **Topography, or the shape of the land surface, can cause differences in local weather and climate (micro-climates). A work area may have two or more distinct micro-climates.**

- **Cloud cover has a definite buffering effect on diurnal (daily) temperature variation. It will lower the daytime high but raise the nighttime low.**

- **Humidity exerts an effect similar to cloud cover on temperature. Humid air takes longer to heat up and cool off and therefore is subject to considerably less daily temperature variation than dry air. Maximum shade temperature rarely exceeds 38°C under high humidity,** while maximums of 54°C are possible under dry conditions.

## Rainfall

In dryland (non-irrigated) areas of the tropics with year-round growing temperatures, rainfall is the major environmental factor that determines which crops can be grown, when they are planted, and what they will yield. Rainfall varies greatly from place to place (often within surprisingly short distances), especially around mountainous or hilly terrain. The dryland farmer is keenly aware of his area's seasonal rainfall distribution. This includes deviations from the normal cycle such as early or late rains, or unseasonable droughts. Too much rain, which can drown out the crop, delay harvest, and accelerate soil erosion, can be just as serious as too little. It may be too wet for plowing one day, yet too dry the following week for good seed germination.

When gathering rainfall data for an area, one should keep in mind that annual rainfall averages have little meaning. Seasonal

**distribution and reliability are far more important in terms of crop production.**

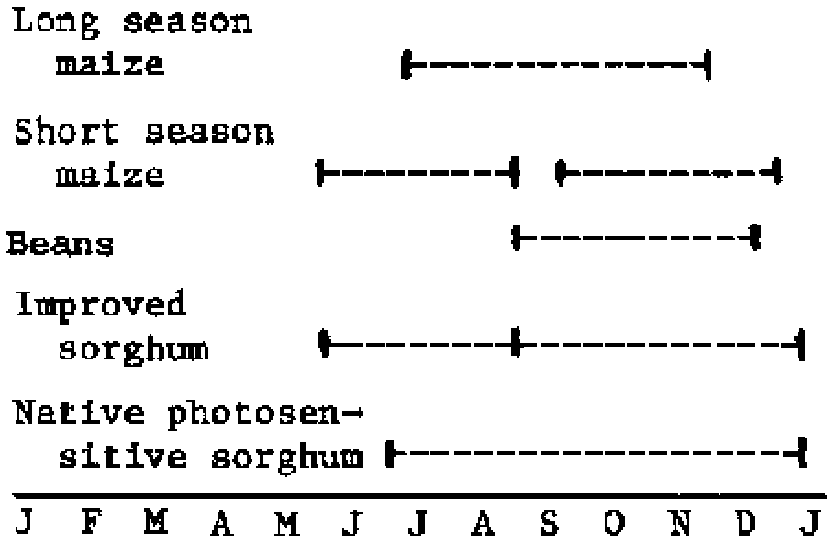
**For example, Ibadan, Nigeria is located in the transition zone between the humid and semi-humid tropics and receives about the same annual rainfall (1140 mm) as Samaru Nigeria, which is located to the north in the savanna zone. Ibadan's rainfall is spread out over nine months from March to November in a bi-modal pattern (i.e., two rainy seasons with a drier period in between). The first season is long enough for a 120-day maize crop, although there is some periodic moisture stress. The second season is shorter, and soil moisture is usually adequate for only an 80-90 day crop. On the other hand, Samaru's equal rainfall is spread out over five months in a uni-modal pattern, providing for a single maize crop not subject to moisture stress.**

**From the example it is apparent that annual rainfall averages alone are not a dependable gauge of the rainfall in an area. The same goes for seasonal rainfall distribution. Although it gives a good general indication of the amount of moisture available for crop production, it does not tell the whole story. The amount of**

**rainfall that actually ends up stored in the soil of a farmer's field for crop use depends on other factors such as water run-off and evaporation from the soil surface, and the soil's texture and depth.**

**When interpreting the rainfall pattern of a work area, it is good to remember that averages are somewhat misleading. Variations to the average can be expected even though the general seasonal distribution curve usually maintains a consistent shape (Figure 1). Cropping cycles and how they relate to the rainfall pattern:**

**Cropping cycles are determined by using the cropping calendar (planting and harvest dates for crops involved), and are closely tied to the seasonal rainfall distribution. This can be seen by comparing the cropping calendar in the next column with the rainfall chart in Figure 1.**




**Crop Calendar, Managua Area of Nicaragua**

**A primary source of rainfall information in a given area is the local farmer. Although official weather station rainfall data is handy to have if it is reliable and representative, it is not essential. Most of the information needed about rainfall distribution can be found by talking to experienced local farmers.**

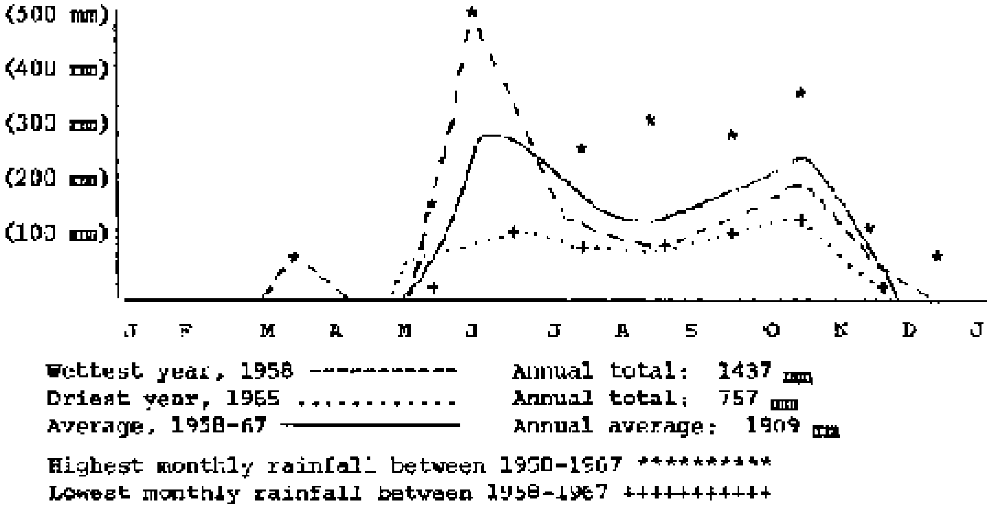



**Figure 1 Monthly Rainfall Pattern, Managua, Nicaragua, 1958-67**

## Humidity

**Relative humidity affects crop production in several ways:**

- **Daily temperature variation is greater under low humidity; high humidity exerts a buffering effect on temperature.**

- **High humidity favors the development and spread of a number of fungal and bacterial diseases (see the disease section in Chapter 6).**

- **The rate at which crops use water is highest under hot, dry conditions, and lowest when it is very humid.**

**Wind and Storm Patterns**

**High winds associated with thunderstorms, hurricanes, and tornados can severely damage crops. Among the reference crops, maize, sorghum and millet are most prone to damage from heavy rain. Hot, dry winds can markedly increase the water needs of crops. The frequency of high winds is also a factor that warrants investigation when surveying a work area's climate.**

**Topography**

**The shape of the land surface influences agriculture by causing local modifications in climate and weather and often is the major factor that determines the suitability of land for various types of farming. A work area may include several topographic features**

**such as mountains, hills and valleys. Individual farms, too, often have significant topographic variations that affect crop production. Mountains and hills can greatly alter rainfall, and it is not uncommon to find a drier, irrigated valley on one side of a mountain range and a wetter, rainfed valley on the other side. Cold air usually settles in valleys, making them considerably cooler than the surrounding slopes. Steep slopes drain rapidly, but are very susceptible to erosion and drought, while flat or sunken areas often have drainage problems. Slopes angled toward the sun are warmer and drier than those angled away from it.**

## Soils

**After climate and weather, soil type is the most important local physical feature affecting cropping potential and management practices. Most soils have evolved slowly over many centuries from weathering (decomposition) of underlying rock material and plant matter. Some soils are formed from deposits laid down by rivers and seas (alluvial soils) or by wind (loess soils).**

**Soils have four basic components: air, water, mineral particles (sand, silt and clay), and humus (decomposed organic matter). A typical sample of topsoil (the darker-colored top layer) contains about 50 percent pore space filled with varying proportions of air and water depending on how wet or dry the soil is. The other 50 percent of the volume is made up of mineral particles and humus. Most mineral soils contain about two to six percent humus by weight in the topsoil. Organic soils like peats are formed in marshes, bogs and swamps, and contain 30-100 percent humus.**

**Climate, type of parent rock, topography, vegetation, management and time all influence soil formation and interact in countless patterns to produce a surprising variety of soils, even within a small area. In fact, it is not uncommon to find two or three different soils on one small farm that differ widely in management problems and yield potential. Important Soil Characteristics**

**There are seven major characteristics that determine a soil's management requirements and productive potential: texture, filth (physical condition), water-holding capacity, drainage, depth,**

**slope, and pH.**

- **Texture refers to the relative amounts of sand, silt and clay in the soil.**

- **Tilth refers to the soil's physical condition and capability of being worked.**

- **Water-holding capacity refers to the ability of the soil to retain water in its spaces.**

- **Drainage refers to the soil's ability to get rid of excess water and affects the accessibility of oxygen to roots.**

- **Depth is the depth of the soil to bedrock and the effective soil depth is the depth to which plant roots can penetrate.**

- **Slope is the inclination of the land surface, usually measured in percentage (i.e., number of meters change in elevation per 100 m horizontal distance).**

- **pH is a measure of the acidity or alkalinity of the soil on** a scale of 0 to 14. These characteristics are discussed in detail in Soils, Crops and Fertilizer Use, U.S. Peace Corps Appropriate Technologies for Development Manual #8, Parts I & II, by D. Leonard, 1969, and Crop Production Handbook, U.S. Peace Corps Appropriate Technologies for Development Manual #6, Unit I, 1969.

## Ecology

For our purposes, ecology refers to the presence of, and interaction among, the reference crops, weeds, insects, diseases, animals (humans, wildlife and livestock), and the environment in general. Agriculture is a perpetual contest with nature and farmers have developed many preventative and control measures, as well as special cropping systems, to give agriculture the advantage over natural succession. Each area will have its own combination of weeds, insects, diseases, and wildlife (including rats and graineating birds) that affect crop production. Identifying these and learning how farmers cope with them is crucial to understanding and dealing with the agricultural environment. The effect of people and agriculture on the overall

**environment**

**Modern technology, land shortages, and increasing populations have increased agriculture's ability and need to "beat back" and manipulate nature. Often little thought is given to the possible environmental consequences of agricultural development. Potential ecological impacts of agricultural projects include:**

- **Deforestation**
- **Soil erosion**
- **Desertification**
- **Laterization**
- **Salinization**
- **Agrochemical poisoning of soil water, animals and people**
- **Flooding.**

**The infrastructure**

**The infrastructure, which refers to the installations, facilities, goods, and services that encourage agricultural production,**

**consists of these elements:**

- **Local farming practices**
- **The physical infrastructure**
- **Land distribution and tenure**
- **Agricultural labor supply**
- **Incentives to farmers.**

**Local Fanning Practices and Systems**

**Farming practices include:**

- **Land preparation-tillage methods, type of seedbed, and erosion control methods**

- **Planting--method, plant population and spacing, choice of variety**

- **Soil amendments--kind, amount, timing, placement of chemical or organic fertilizers and liming materials**

- **Control of weeds, insects, diseases, birds, rodents and**

**nematodes (tiny, parasitic roundworms that feed on plant roots).**

- **Special practices such as irrigation or "hilling up" maize**

- **Harvest and storage methods.**

**The terms "cropping system" not only refers to the overall cropping calendar (planting and harvest dates for the crops involved) but more specifically to the actual crop sequences and associations involved, namely:**

- **Monoculture versus crop rotation--Monoculture is the repetitive growing of the same crop on the same land year after year. Crop rotation is the repetitive growing of an orderly succession of crops (or crops and fallow) on the same land. One crop rotation cycle often takes several growing seasons to complete (for example, maize the first two years, followed by beans the third and cotton the fourth).**

- **Multiple Cropping--There are two types of multiple** cropping. One is sequential cropping, which means growing two or more crops in succession on the same field per year or per growing season. The other is intercropping, which is the most common definition of multiple cropping and involves the growing of two or more crops at the same time on the same field. See Chapter 4 for details on the different types of intercropping.

Due to differences in soils, climate, management ability, available capital, and attitudes, important differences in farming practices and systems may be found within a particular area.

## The Physical Infrastructure

The physical infrastructure refers to the physical installations and facilities that encourage agricultural production such as transportation (farm-to-market roads, railroads), communications, storage and market facilities, public farm works (regional irrigation, drainage, and flood control systems), and improvements to the farm (fencing, wells, windbreaks, irrigation and drainage systems, etc.). All of these are important, but

**adequate and reasonably priced transport is especially critical since agriculture is a business that involves handling bulky materials. A farmer's distance from the road network is often the prime factor determining whether or not he or she can profitably use fertilizer or move his or her surplus crops to market.**

## Land Distribution And Tenure

**In a settled area, all the agricultural land may be occupied. The land distribution and tenure situation in an area thus has enormous social and economic consequences and greatly affects farmer incentives. The two most important issues in this regard are:**

- **Who occupies the land and on what terms do they use it or allow others to use it?**

- **What is the ratio between the number of people dependent on farming for their livelihood and the amount and kinds of land available?**

## The Agricultural Labor Supply

**The ratio of farmers and farm laborers to the amount and types of land provides a good indication of land use intensity. The existence of adequate farm labor for peak periods is another important consideration affecting farm practices and returns. For most of the year, many farming areas in developing countries have a generally high rate of agricultural underemployment, except during a few peak periods such as planting at the start of the rains or weeding time, if mechanical cultivation is not used. At these times, the scarcity of labor can become the most critical factor limiting production, and labor productivity assumes an unusual importance.**

## Incentives for Farmers

**These can be very broadly interpreted, since they include equitable land tenure and distribution, adequate markets and prices for farm produce, and the existence of a viable improved technology.**

## Understanding the individual farm unit

**Each farm has its own unique characteristics, but those located in the same area usually share enough similarities to allow grouping them into several general types of farm unit, such as subsistence, marketoriented field crop, plantation, etc. If an area's environment is fairly uniform, only one type of farm unit may predominate. If it is characterized by irregular topography and lopsided land distribution, the area may have two or more types of farm units.**

**There are eight basic criteria that can be used to differentiate types of farm units:**

- **Location**
- **Type of occupancy**
- **Size of farm, parcelling, and land use potential**
- **Size of the farm business**
- **Type of farm enterprise**
- **Production practices**
- **Farm improvements**
- **Farm labor supply.**

**Location**

**The principal factors here are:**

- **Natural characteristics such as soil type, slope, soil depth, drainage, access to water, etc.**
- **Proximity to the transportation network and other facilities such as public irrigation and drainage systems**
- **Location in relation to other farm units**
- **Local name of the farm's location.**

**Type of Occupancy**

**The principal considerations are:**

- **Who owns the land?**
- **If not owner-operated, what is the tenancy arrangement (i.e., cash rent, crop share, or work share) and on what**

**specific terms? How secure is the arrangement?**

- **If no one has legal title to the land, is it occupied under squatters' rights that are protected by law?**

- **Who manages the farm unit and makes the basic decisions?**

## Size of Farm

- **Total farm size in terms of local units of measure**

- **Location of farm parcels: If they are dispersed, how far are they from the farmer's house?**

- **Actual land use: tillable versus pasture versus forest; irrigated versus non-irrigated**

- **Characteristics of its soils: local name, color, texture, depth, drainage, slope, plus farmer's opinion of them.**

## Size of Farm Business

- **Land value of the farm unit**

- **Value of other fixed assets**

- **Amount of operating capital employed per land or livestock unit**

- **The value of production per land or livestock unit. The value of the farm unit compared to its number of workers indicates whether it is capital-intensive (using machines and money to harvest) or laborintensive (using human labor to perform farm operations). The value of production per land unit indicates the intensity of land use.**

**Type of Farm Enterprise**

**Some farms are engaged in only one enterprise such as growing sugarcane, coffee, rice, etc., but this type of monoculture is unusual among small farms. More likely, some form of mixed agriculture will exist. The main considerations are:**

- **Relative importance of each enterprise**

- **The yields obtained from each enterprise**

- **The disposal of the products from each enterprise (subsistence or cash sale) and where sold**

- **Crop rotations and associations**

- **Relationship between crop and livestock production, if any.**

**Production Practices**

- **The specific factors used in agricultural development**
- **Rate, method, and time of application.**

**Farm Improvements**

- **Condition of the farm family home (or the farm manager's and farm workers' homes).**

- **Presence and condition of fences, wells, irrigation works, field access roads, storage facilities, livestock shelters,**

**corrals, etc.**

**The Farm Labor Supply**

- **Degree of reliance on the family's own labor force and the composition of that force**

- **Degree of dependence on hired labor**

- **The seasonal nature of work requirements**

- **Use of animal or tractordrawn equipment.**

**Guidelines for the orientation of the extension worker**

**These guidelines are designed to help newly assigned agricultural field workers (AFW) orient themselves to the local agro-environment and its individual farm units within one or two months after arrival in the area. When using the guidelines, keep in mind the following:**

- **Do not undertake a highly detailed survey of local**

**resources at the start of the assignment unless the host agency specifically requests it. Such a survey is likely to arouse local suspicions, especially if you are overzealous or overbearing with your initial contacts.**

- **The host agency may provide a basic orientation to the work area, but it may be very limited.**

- **If there are discrepancies between the information gathered from local sources (farmers, etc.) and that from outside or official sources, trust the local "grass roots" information until proven otherwise. Local farmers are the ultimate authorities on the local environment.**

- **The guidelines that follow are organized mainly by subject area but do not have to be followed in a set order. You will be picking up bits and pieces of information from a single informant that may deal with a number of areas, and you will have to put them into their proper context.**

## Introductory orientation

**This initial phase focuses on the agricultural environment in general and is designed to help you familiarize yourself with it and adjust your work schedule and activities to the seasonal rhythm of the area's agriculture. Unless severely limited by your local language ability, you should be able to complete this phase in two to four weeks if you spend several hours a day talking with local farmers and other sources of agricultural information throughout the area.**

## Establish Communication

**A major part of your time will be spent talking with and listening to farmers and other knowledgeable sources (local residents) who have a vested interest in agriculture.**

## Locate Farmers

- **Get a general idea of how farmers are distributed geographically.**
- **Get a specific idea of where likely client farmers are located (i.e., those with whom your job description deals).**

**Locate Other Knowledgeable Individuals Agricultural technicians stationed or working in the area, local buyers of farm produce, agricultural supply dealers, and truckers are good sources of information. Select Reliable Local Sources**

**At the early stage, your contacts do not have to be completely representative so long as they are knowledgeable. The best farmerinformants are usually among the more progressive farmers. For example, a progressive small farmer will provide more information and insight into small farming operations than a larger-scale commercial farmer. Likely initial contacts are: your landlord's relatives, the local mayor or other local official, the more easily accessible and talkative farmers, or farmers who have worked with extension services for some time. Keep a careful record of all initial contacts.**

**How to Interview**

- **Introducing yourself--Ideally, you should have a third party make the initial contact and introduction. If this is** not possible, be prepared with a practiced explanation of your presence. It is important that you emphasize that you are the learner at this stage.

• Suggested techniques--Allow the farmer to talk as spontaneously as possible. Any leading questions almost always get "yes" responses. Use a memorized interview schedule rather than a written one which is likely to inhibit responses. Avoid over-familiarity.

• It is generally not a good idea to take written notes in front of a farmer, although in some cases he may expect you (as a "technician) to do so. Some farmers may view written notes as having some possible conncection with future tax collections, etc. It's best to wait until an unobtrusive moment such as the mid-day break to summarize information in written form.

## Become Familiar With the Principal Physical Features

In order to locate farms, farmers, agricultural suppliers, etc., you

**should pinpoint their locations with reference to roads and trails and dominant topographic features. The principal physical and demographic features of the work area should also be located and understood. These include:**

- **Topographical features-altitude, streams, principal features (landmarks) recognized locally as reference points, valleys, farm and non-farm lands**

- **Communications (roads and trails)--seasonal access, distances, travel times-and modes of travel between points**

- **Demographic--locations of communities (and their local names), farmers**

- **Infrastructure--irrigation systems, drainage systems, agricultural supply stores, schools, extension offices, etc.**

**You can make a base reference map yourself which shows these features, relying on your own observations as well as road maps, geographic maps, or soil survey/land use maps available from**

**government agencies and international or regional organizations working in the area.**

**Become Familiar With Climate and Weather Patterns**

**Sources of Information**

- **Weather station records-Obtain all available meterological data from the official weather station nearest to your area of assignment. Its orientation value will depend on the station's proximity and how well it represents your area's conditions.**

- **Relief maps--Altitude is the main temperature determinant in the tropics; remember that for every 100 m rise in altitude, average (mean) temperature will drop about 0.65°C.**

- **Local farmers--Official weather data can be valuable, but it is not essential. Information about local climate and weather conditions can be learned from experienced local farmers.**

**You can draw a rainfall chart which is accurate enough for the initial orientation simply by systematically recording farmer's comments about the seasonal distribution of rainfall; the same can be done for seasonal temperature variation.**

**Climate and weather checklist**

**Make tables and/or charts showing the monthly distribution of rainfall using these criteria:**

- **Dry to wet scale: (See rain fall section, Chapter 2.)**
- **Rainfall frequency: the number of times it normally rains in a week or month**

**Risk factors associated with climate and weather (i.e., droughts, hail, high winds, flooding) can be established by having farmers recall bad crop years over a span of years. Be sure to distinguish weather factors from other causes such as insects and diseases.**

**As for temperature, be sure to record:**

- **Monthly temperature averages.**

- **Periods of significantly high or low temperatures.**
- **Occurrence of first and last killing frosts if applicable**

**Become Familiar With Prevailing Fanning Systems and Practices**

**Identify the major crop and livestock enterprises in the work area. For each of the crop enterprises which predominates in the area, indicate the following and note any local variations:**

- **The growing season--Indicate the normal growing season and its variations (early-late), and make a cropping calendar using line bar graphs (see rainfall section, Chapter 2).**

- **Describe production practices --Do not confuse the practices recommended by extension with those generally accepted by farmers. Your interest is in the prevailing practices used by most of the farmers in the area. Make note of any significant differences among different groups of farmers.**

- **Describe the principal-land preparation practices--**

Specify the earliest and latest dates of application and indicate what the practices are called locally. For example, in many areas of Central America, the practice of hilling up maize (throwing soil into the row) is called "aprogue".

- Describe the kind and amount of inputs associated with the practice. This includes the amount applied, method and timing of application, and worker-days of labor.

Estimate yields and returns

At this stage of the orientation, it is not necessary to make a detailed account of costs and returns. Seeking such data can arouse local suspicions or fears of future tax levies. Rough estimates of production costs, and gross and net returns are sufficient.

- Record reported yields per unit of land.

- Record recent prices at normal time of sale.

- Multiply recent prices by approximate average yield to

**get approximate gross returns.**

- **Subtract approximate production costs from gross returns to obtain approximate net returns. There are two ways to do this: net return to capital, land, and family labor where the only labor costs you account for are hired labor, or net return to land and capital in which case an opportunity cost (exchange value) must be assigned to family labor and subtracted from the gross return. The first way is the easiest.**

**Indicate the relative tendencies of production**

- **Estimate the percentage of the crop that is marketed.**

- **Identify the principal local market outlets (buyers).**

- **Indicate the seasonal movement of production off the farms: is it sold at harvest, some sold at harvest, some held for higher prices, etc.?**

- **Indicate the seasonal price fluctuations (average over**

**several years).**

**List the outside production inputs which are available locally. ("Available" means when needed.)**

- **Crop production supplies (give brands, grades, and unit prices): fertilizers, insecticides, fungicides, herbicides, hand tools, handoperated equipment, seeds, etc.**

- **Agricultural machinery and equipment (if used): tractors (horsepower and make), implements, irrigation pumps, etc.**

- **Services: such as custom machinery services and rates charged, and professional services (indicate whether public or private), technical assistance and soil testing, etc.**

**Summarize the Information**

**Every area's agriculture is tuned to a time schedule or seasonal rhythm to which work schedules and activities must be adjusted.**

**Getting oriented in time is vital to effective agricultural extension. The best way to do this is to summarize the initial phase of orientation by making graphs and calendar charts that show the area's seasonal rhythm of climate, agriculture, and social life. The following graphs, charts, and observations were made by a group of Peace Crops Volunteers assigned as rural credit agents in the Pacific region of Nicaragua during an orientation-training exercise. The principles involved apply worldwide.**

**Make a generalized climate and weather calendar**

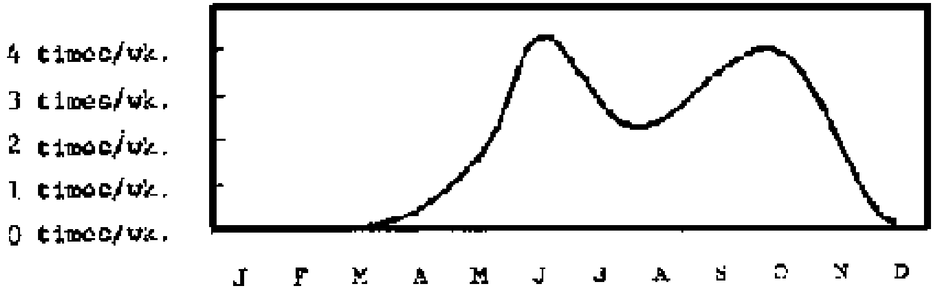
**Chart the normal monthly distribution of rainfall as related by farmers using terms such as wet, dry, some rain, wettest time, rainfall drops off, etc. There are three ways to do this:**

**1. Use the frequency of rainfall to measure seasonal distribution (see chart above).**

**2. Use a dry-to-wet scale.**

**3. Measure rainfall, if you have access to reliable**

**meteorological data. Indicate the range and frequency of possible deviations from normal rainfall patterns from information passed on to you from farmers, or recorded by a weather station. (See chart above.)**




**Frequency of Rainfall**

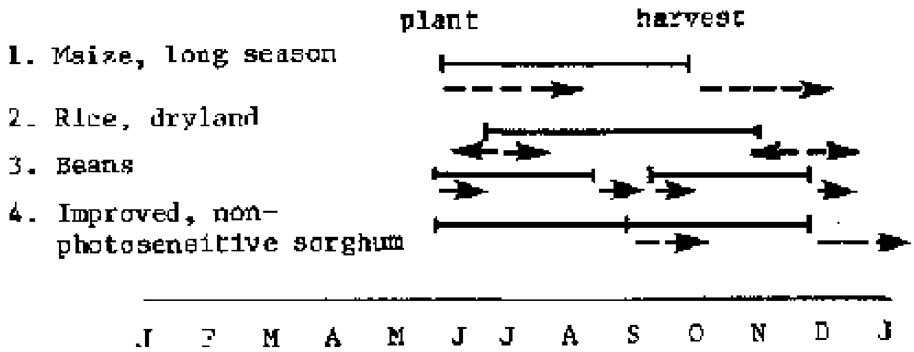
**Make a calendar of agricultural activity.**

**For each of the major crop enterprises, display the length and possible range of growing season, including likely variations in planting and harvest times.**

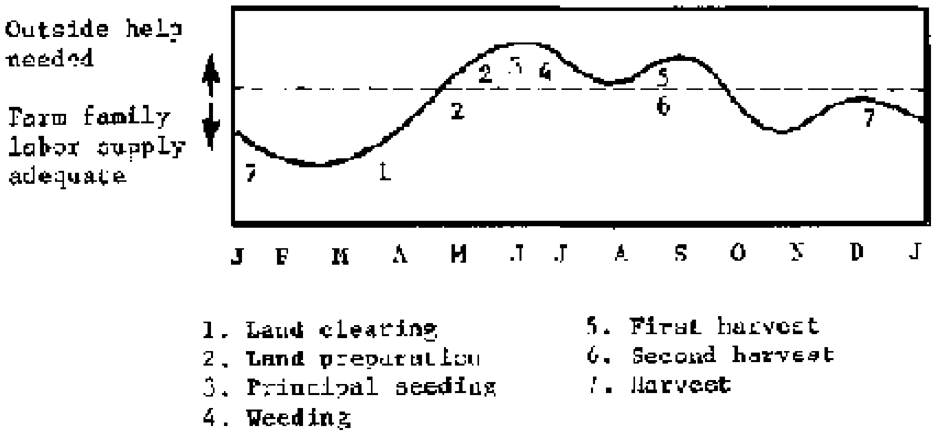
**(See example at the top of page 31.)**

**Indicate the time for performing critical operations and relative labor requirements of those operations.**

**(See example at the bottom of page 31.)**




**Example: Crop Calendar, Crops and Order of Importance in the Esteli Area of Nicaragua**




**Example: Distribution of Work and Timing of Principal Farming Operations in the Esteli Area of Nicaragua**

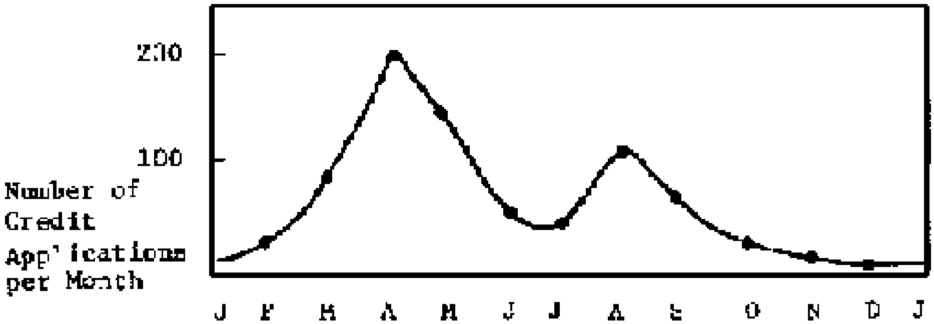
**Indicate the relative seasonal labor demand, whether there are any periods of labor movement into or out of the area.**

**Determine the seasonal demand for other critical inputs: keep in mind an input is not considered critical unless farmers feel it is. (For example, if fertilizer is not generally used, it is not presently a critical input.)**

**Make a calendar of economic activity related to agriculture.**

> **Indicate relative demand for short-term production credit. (See example below.) Indicate seasonal marketing patterns (the rate at which the crop is marketed).**
>
> **Graph the seasonal range of prices.**

**Make a calendar of social activity that includes religious holidays and other holidays or seasonally determined social obligations. The summary concludes the initial orientation phase. With a good understanding of the local agricultural environment and farming practices, you are ready to move on to the next step: orientation to the individual farm unit.**




**Example: Demand for Production Credit, Branch Office of the National Bank of Nicaragua**

## Orientation to the farm unit

**Learning to communicate effectively with individual farmers about their farm enterprises and their farm businesses will help move you out of the questioning stage into a more active role. Expressing an interest in and being knowledgeable about the farm business can be the means as well as the purpose of communicating with farmers and will definitely increase your rapport and credibility with them.**

## Describe Typical Farm Units

**Make a general farm profile which is representative for each of the types of farm unit with which you will be working.**

**Describe the Annual Agricultural Cycle as Perceived By the Farmer**

**For each type of farm unit with which you are likely to work, make an annual diary which indicates:**

- **Normal operations by months or seasons**
- **The decisions which the farmer has to make that are related to these operations**
- **The farmer's concerns throughout the year, such as the timing of the rains, dry spells, bird damage to crops, flooding, obtaining inputs, completing operations in time, etc.**

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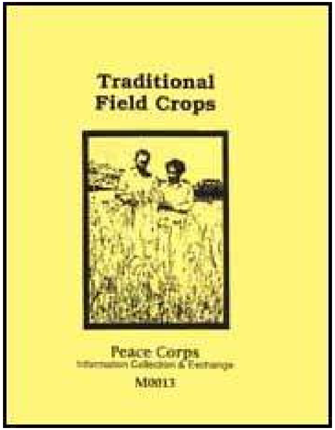
**Traditional Field Crops (Peace Corps, 1981,**






**Traditional Field Crops (Peace Corps, 1981, 283 p.)**

**An introduction to the reference crops**

**There are several reasons why the six reference crops -maize, grain sorghum, millet, peanuts, field beans, and cowpeas -are grouped together in one manual. All of the reference crops are row crops (grown in rows) and because of this, they share a**

**number of similar production practices. Also, in developing nations, two or more of the crops are likely to be common to any farming region and are frequently interrelated in terms of crop rotation and intercropping (see Chapter 4, page 91) In addition, all of them are staple food crops. The developing countries are major producers of the reference crops, with the exception of maize.**

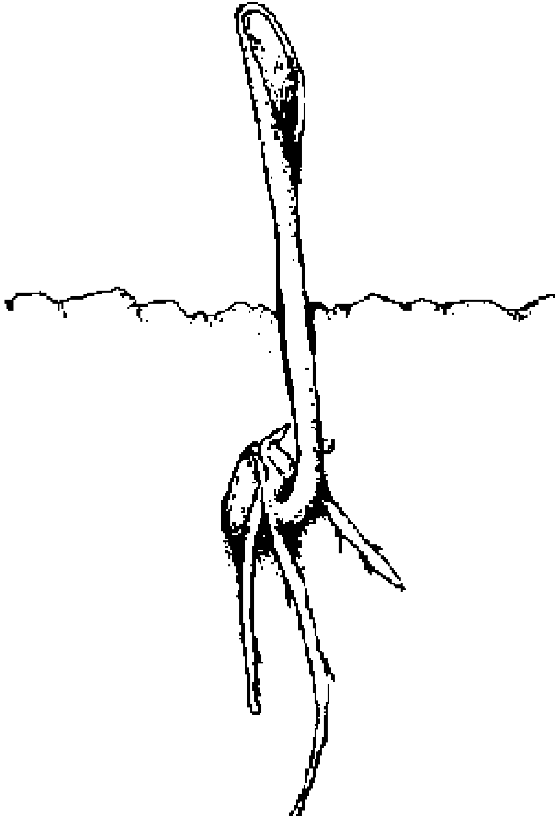
**Cereal crops versus pulse crops**

**Maize, grain sorghum, and millet are known as cereal crops, along with rice, wheat, barley, oats, and rye. Their mature, dry kernels (seeds) are often called cereal grains. All cereal crops belong to the grass family (Gramineae) which accounts for the major portion of the monocot (Monocotyledonae) division of flowering (seed-producing) plants. All monocot plants first emerge from the soil with one initial leaf called a seed leaf or cotyledon.**

**A germinating maize seedling; note that it has only one seed leaf, which makes it a monocot. Monocots emerge through the soil**

**with a spike-like tip. They generally have fewer problems with clods and soil dusting than dicots.**

**Peanuts, beans, and cowpeas are known as pulse crops, grain legumes or pulses, along with others such as lima beans, soybeans, chickpeas, pigeonpeas, mung beans, and peas. The pulses belong to the legume family (Leguminosae) whose plants produce their seeds in pods. Some legumes like peanuts and soybeans are also called oilseeds because of their high vegetable oil content.**



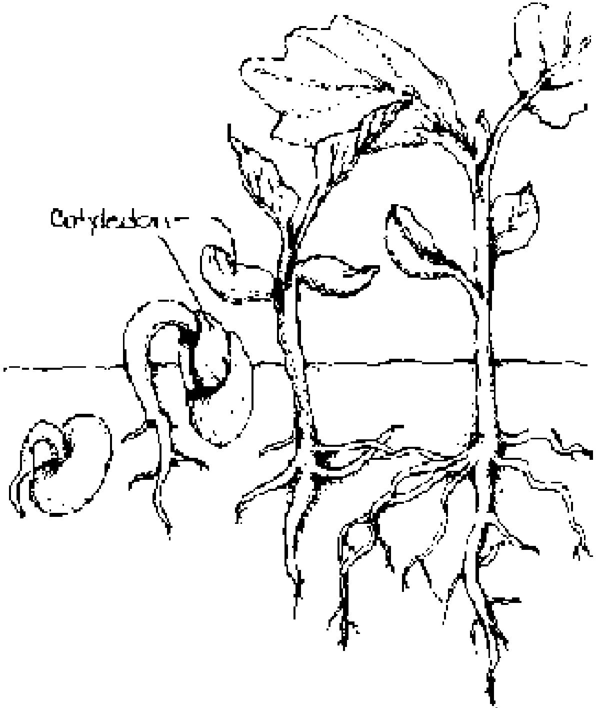
**Germinating maize seed**

## Table 2 World and Regional Production of the Reference Crops

**(1977 FAO data)**

| **Crop** | **Total World Production (millions of metric tons)** | **Percent of World Production Developing Countries** | **Developed Countries** |
|---|---|---|---|
| MAIZE | 350.0 | 32.4 | 67.6 |
| GRAIN SORGHUM | 55.4 | 59.9 | 40.1 |
| MILLET | 42.9 | 95.1 | 4.9 |
| PEANUTS (Groundnuts) | 17.5 | 88.2 | 11.8 |
| FIELD BEANS, COWPEAS | 12.9 | 86.1 | 13.9 |

**A germinating bean plant; note the two thick cotyledons (seed leaves) which originally formed the two halves of the seed.**




**Geminating bean seed**

**The pulses belong to the other major division of flowering plants called dicots (Dicotyledonae). Unlike the monocots, dicot plants first emerge from the soil with two seed leaves.**

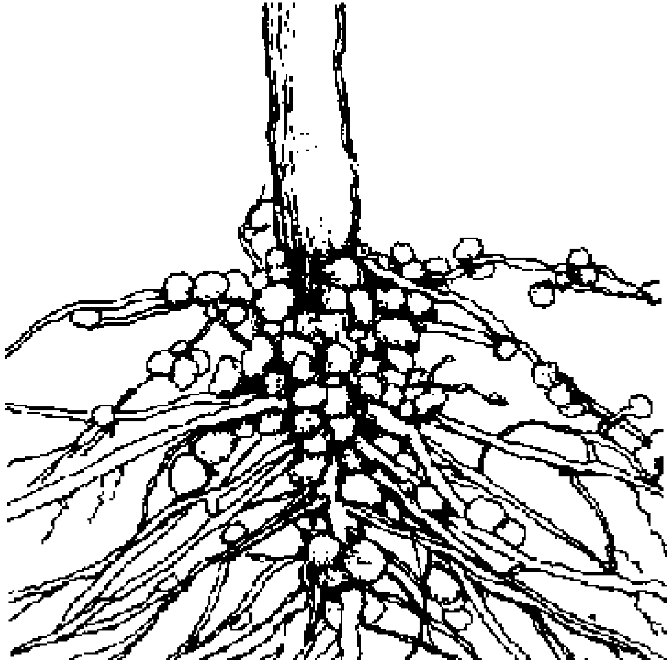
**In addition, the pulses have two outstanding characteristics for farmers and for those who consume them:**

- **They contain two to three times more protein than cereal grains (see Table 3)**

- **Legumes obtain nitrogen for their own needs through a symbiotic (mutually beneficial) relationship with various species of Rhizobia bacteria that form nodules on the plants' roots (see illustration on page 38).**

**Nitrogen is the plant nutrient needed in the greatest quantity and is also the most costly when purchased as chemical fertilizer. The Rhizobia live on small amounts of sugars produced by the legume and, in return, convert atmospheric nitrogen (ordinarily unavailable to plants) into a usable form. This very beneficial process is called nitrogen fixation. In contrast, cereal grains and other non-legumes are totally dependent on nitrogen supplied by the soil or from fertilizer.**

**Nitrogen-fixing nodules on the roots of a bean plant. Note that they are attached to the roots rather than an actual part of them.**



**Nitrogen fixing nodules**

**Despite the urgent need to increase both cereal and pulse**

**production in the developing countries, most crop improvement efforts of the "Green Revolution" emphasized the cereals (see page 294). As a result, pulse yields in the region have shown little, if any, increase. In some areas, total pulse production has actually declined in favor of the cereal grains, even though many developing nations suffer from a chronic protein shortage. Fortunately, this situation is now being reversed.**

**The nutritional value of the reference crops**

**The cereal grains, with their high starch content and lower prices, make up a major source of energy (calories) in developing countries. There, cereal consumption is high enough to contribute a substantial amount of protein to the diets of older children and adults (although still well below quantity and quality requirements). Another plus is that cereal grains contain a number of vitamins and minerals, including Vitamin A which can be found in the yellow varieties of maize and sorghum. gained from eating large quantities of the cereals, their protein content is relatively low (7-14 percent) and they are deficient in several amino acids. Infants and children, who have much higher protein**

**needs per unit of body weight and smaller stomachs, do not get as much protein from cereals as adults. Studies have also shown that some reference crops lose vitamins and protein in substantial amounts with traditional preparation methods (milling, soaking, and drying).**

**The pulses have considerably higher protein contents than the cereal grains (17-30 percent in the reference pulses) and generally higher amounts of B vitamins and minerals. Unfortunately they also may have some deficiencies in amino acids.**

**All animal proteins (meat, poultry, fish, eggs, milk and cheese) are complete proteins (contain all essential amino acids), but their high cost puts them out of reach of much of the population in developing nations.**

**Fortunately, it is possible to satisfy human protein requirements without relying solely on animal protein sources. The cereals and pulses, though not complete proteins in themselves, can balance out each other's amino acid deficiencies. Cereals are generally**

**low in the essential amino acid lysine, but relatively high in another, methionine. The opposite is true for most of the pulses. If eaten together or within a short time of each other and in the right proportion (usually about a 1:2 ratio of pulse to cereal), combinations like maize and beans or sorghum and chickpeas are complete proteins. In most developing countries, however, pulses are more expensive than the cereal grains, which creates difficulties in achieving a balanced diet.**

**Table 3 Nutritional Value of the Reference Crops (dry weight basis)**

| Crop | Percent Protein | Calories/100 grams | Calories/lb. |
|---|---|---|---|
| MAIZE | 8-10 | 355 | 1600 |
| GRAIN SORGHUM | 7-13 | 350 | 1600 |
| MILLET (Pearl) | 10-13 | 330 | 1500 |
| COMMON BEANS | 21-23 | 340 | 1550 |
| COWPEAS | 22-24 | 340 | 1550 |
| PEANUTS | 28-32 | 400 | 1800 |

| | | | |
|---|---|---|---|
| (GROUNDNUTS) | | | |

**An introduction to the individual crops**

**Maize (Zea mays)**

**Distribution and Importance**

**In terms of total world production, maize and rice vie for the number two position after wheat. Several factors account for the importance of maize:**

- **Maize can adapt to a wide range of temperature, soils and moisture levels and resists disease and insects.**
- **It has a high yield potential.**
- **It is used for both human and animal consumption.**

**Types of Maize**

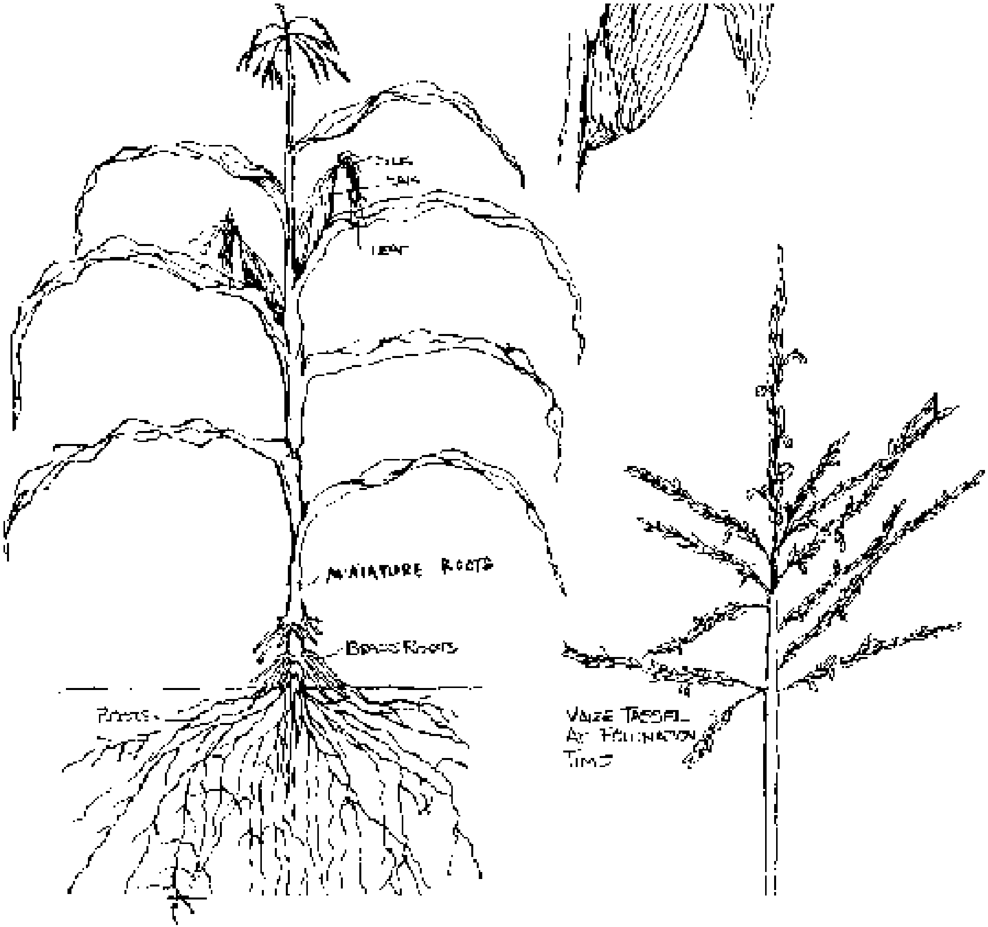
**There are five principal types of maize:**

- **Dent: The most widely grown type in the U.S. The seed has a cap of soft starch that shrinks and forms a dent at the top of the kernel.**

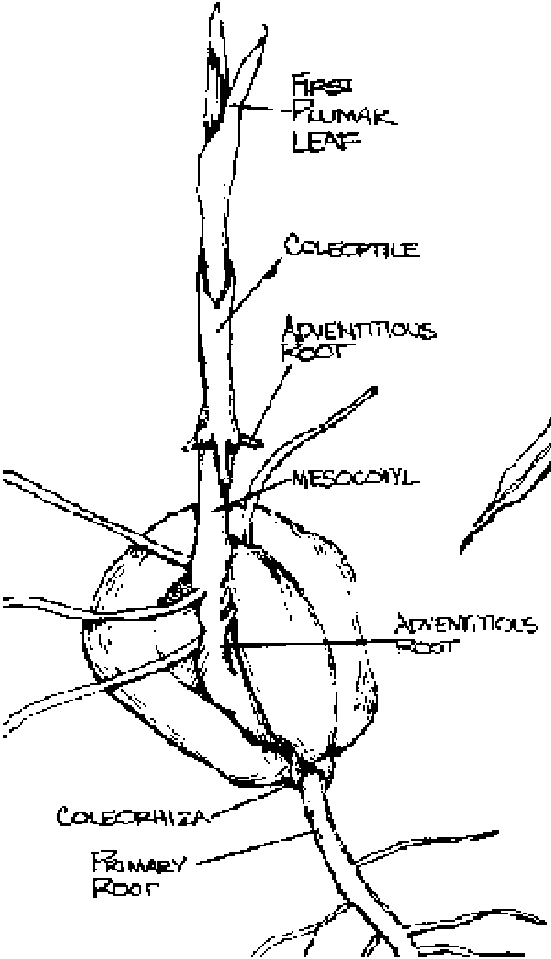
- **Flint: Widely grown in Latin America, Asia, Africa and Europe. The kernels are hard and smooth with very little soft starch. It is more resistant to storage insects like weevils than dent or floury maize.**

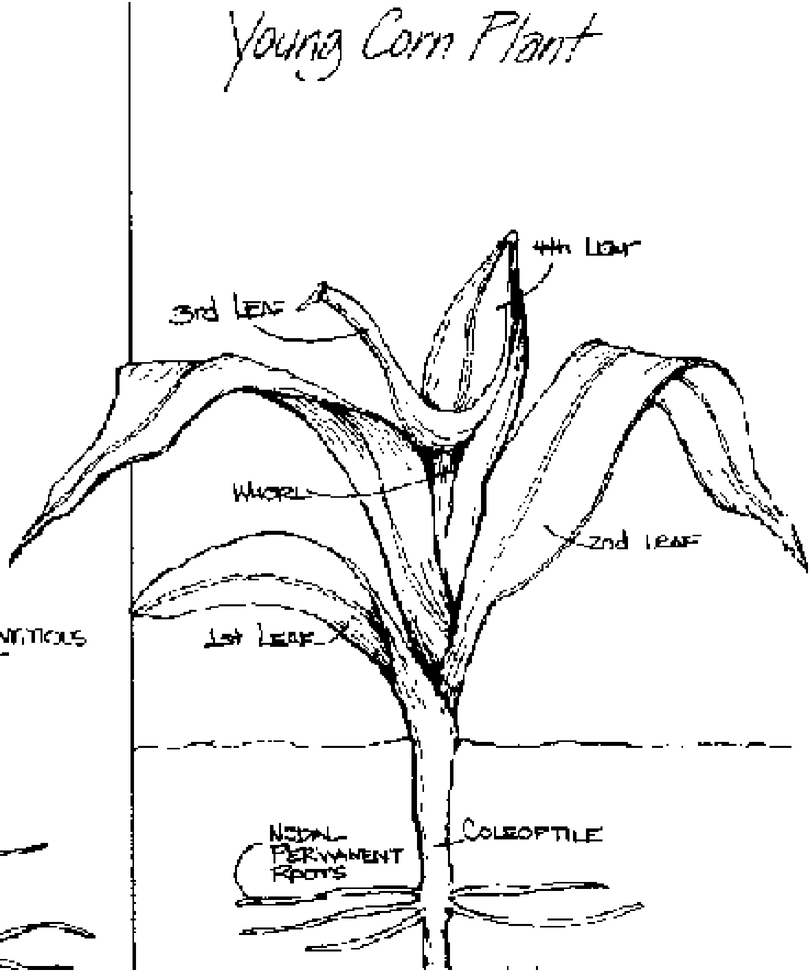
- **Floury: Mainly soft starch and widely grown in the Andean region of South America. It is more prone to storage insects and breakage than harder types.**

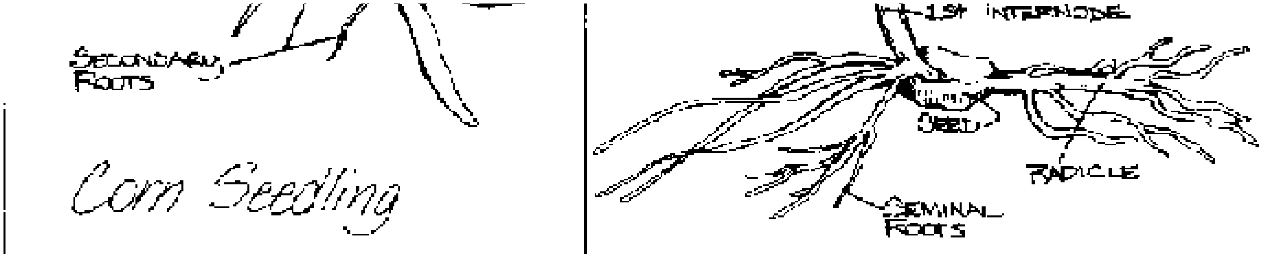
**An ear of maize. Each silk leads to an ovula (potential kernel) on the cob. Varieties vary in length and tightness of husk covering, which determines resistance to insects and moisture-induced molds which may attack the ear in the field.**



## Maize tassel, ear of maize


FIRST
PLUMAR
LEAF
COLEOPTILE
ADVENTITIOUS
ROOT
MESOCOTYL
ADVENTITIOUS
ROOT
COLEORHIZA
PRIMARY
ROOT


Young Corn Plant
4th LEAF
3rd LEAF
WHORL
2nd LEAF
1st LEAF
COLEOPTILE
NODAL
PERMANENT
ROOTS




**Parts of young maize plants**

- **Pop: Really an extreme form of flint maize.**

- **Sweet: At least twice as high in sugar as ordinary maize and meant to be consumed in immature form when only about one-third the potential grain yield has been accumulated. It is more prone to field insect damage, especially on the ears.**

**A potentially very valuable type called hi-lysine maize with more than double the content of lysine is nearing the mass application stage, but still has some field and storage problems to overcome (see the section on maize improvement at the end of this chapter).**

## Maize Yields

**Average yield of shelled grain (14 percent moisture) under varying conditions are shown below.**

### Average Yield of Shelled Grain

| | **lbs./acre** | **kg/hectare** |
|---|---|---|
| Top farmers in the U.S. Corn Belt | 9,000-12,000+ | 10,000-13,500 |
| U.S. Average | 5,050 | 5,700 |
| Average for developed countries | 4,200 | 4,700 |
| Average for LDC's | 450-1,350 | 500-1,500 |
| Feasible yield for small scale LDC farmers with improved practices | 3,500-5,500 | 4,000-6,000 |

**Source: FAO and USDA data, 1977.**

### Climatic Requirements of Maize

**Rainfall: Nonirrigated (rainfed) maize requires a minimum of around 500 mm of rainfall for satisfactory yields. Ideally, the bulk of this should fall during the actual growing season, although deep loamy or clayey soils can store up to 250 mm of pre-season rainfall in the future crop's root zone. Any of the following factors will act to increase the moisture needs of maize (and other crops):**

- **Long growing periods due to cool temperatures.**
- **Shallow and/or sandy soils with low water-holding ability.**
- **Excessive water runoff due to lack of erosion control on sloping land.**
- **Low humidity, especially when combined with wind.**

**Maize has some ability to resist dry spells but is not nearly as droughttolerant as sorghum and millet.**

**Temperature: The optimum growth rate of maize increases with temperatures up to about 32-35°C if soil moisture is abundant, but decreases slightly with temperatures around 27-30°C when**

**soil moisture is adequate. If soil moisture is low, the optimum growth rate temperature drops to 27°C or below. At temperatures of 10°C or below, maize grows slowly or not at all and is susceptible to frost. However, daytime temperatures in excess of 32°C will reduce yields if they occur during pollination.**

**Yields are also reduced by excessively high nighttime temperatures, since they speed up the plant's respiration rate and the "burning up" of the growth reserves.**

**Soil requirements: Maize grows well on a wide variety of soils if drainage is good (no waterlogging). It has a deep root system (up to 185 cm) and benefits from deep soils which allow for improved moisture storage in dry spells. The optimum pH for maize is in the 5.5-7.5 range, although some tropical soils produce good yields down to a pH of 5.0 (very acid). The liming and nutrient needs of maize are covered in Chapter 5.**

**Response to Daylength: The length of growth period of many plants is affected by daylength. This is known as a photosensitive (photoperiodic) response. Most maize varieties are short day**

**plants which means that they will mature earlier if moved to a region with significantly shorter daylengths than they were bred for. In the tropics, there is relatively little variation in daylength during the year or between regions. Because most temperate zone maize varieties are adapted to the longer daylengths of that area's summer, they will flower and mature in too short a period for good yield accumulation if moved to the tropics. Sweet maize seed from the temperate zone may reach little more than knee height in the tropics, and produce disappointingly small ears, although in record time' Likewise, the "giant" novelty maize advertised in some gardening magazines is nothing more than a variety adapted to the very short daylengths of the tropics. When grown in the temperate zone, the much longer daylengths retard maturity and favor vegetative growth. Some maize varieties, however, are day neutral with little response to variations in daylength.**

**As mentioned earlier, maize's relatively low protein and high starch content makes it more important as an energy (calorie) source. Many people believe that yellow maize has more protein than white maize, but the only nutritional difference between the**

**two is the presence of Vitamin A in the yellow variety (also called carotene).**

**Unlike production in the developed countries, maize production in developing countries is almost entirely used for human food in the form of meal, flour, tortillas or a thick paste. In humid areas where increased spoilage problems make grain storage more difficult, a significant portion of maize may be consumed much like sweet corn while it is still in the semi-soft, immature stage.**

**Maize has numerous industrial and food uses in the form of some 500 products and by-products. Various milling and processing methods can produce starch, syrup, animal feed, sugar, vegetable oil, dextrine, breakfast cereals, flour, meal, and acetone. Maize also is used for making alcoholic beverages throughout the world. Maize Stages of Growth Depending on the variety and growing temperatures, maize reaches physiologic maturity (the kernels have ceased accumulating protein and starch) in about 90-130 days after plant emergence when grown in the tropics at elevations of 0-1,000 meters. At higher elevations, it may take up to 200-300 days. Even at the same elevation and temperature,**

**some varieties will mature much earlier than others and are known as early varieties. The main difference between an early (90-day) and a late (130-day) variety is in the length of time from plant emergence to tasseling (the vegetative period). This stage will vary from about 40 to 70 days. The reproductive period (tasseling to maturity) for both types is fairly similar and varies from about 50 to 58 days. The following discussion describes the growth stages and related management factors of a 120day maize variety.**

## PHASE I: FROM GERMINATION TO TASSELING

**Plants will emerge in four to five days under warm, moist conditions but may take up to two weeks or more during cool or very dry weather. Little if any germination or growth occurs at soil temperatures below 13°C. Harmful soil fungi and insects are still active in cool soils and can cause heavy damage before the seedlings can become established. Fungicide seed treatments (see Chapter 6) are usually most beneficial under cool, wet conditions and may increase yields from 10 to 20 percent.**

**Maize seeds are large and contain enough food reserves to sustain growth for the first week or so after emergence. Then the plants must rely on nutrients supplied by the soil or fertilizer. Up until kneehigh stage, the three major nutrients -nitrogen, phosphorus, and potassium - are required in relatively small amounts, but young seedlings do need a high concentration of phosphorus near their roots to stimulate root development.**

**The primary roots reach full development about two weeks after seedling emergence and are then replaced by the permanent roots (called nodal roots) which begin growing from the crown (the underground base of the plant between the stem and the roots). Planting depth determines the depth at which the primary roots form but has no effect on the depth at which the permanent roots begin to develop.**

**Until the plants are knee high, the growing point (a small cluster of cells from which the leaves, tassel, and ear originate) is still below the soil surface, encased by a sheath of unfurled leaves. A light frost or hail may kill the above-ground portion of the plant, but usually the growing point (if below ground) will escape**

**injury, and the plant will recover almost completely. However, flooding at this stage is more damaging than later on when the growing point has been carried above ground by the stalk.**

**The growing point plays a vegetative role by producing new leaves (about one every two days) until the plants are knee high; then a major change occurs. Within a few days, the underground growing point is carried above ground by a lengthening of the stalk and switches from leaf production to tassel initiation within the plant. (Slit a plant lengthwise at this stage, and you can easily see the growing point as a peaked tip inside the stalk). At this time roots from adjacent rows have reached and crossed each other in the between-row spaces (for rows up to one meter wide).**

**From tassel initiation until tassel emergence takes about five to six weeks and is a period of very rapid growth in plant height, leaf size, and root development. Maximum root depth can reach 180 cm. under optimum soil, moisture, and fertility conditions and is attained by the time of tassel emergence.**

**Maximum nutrient uptake occurs from about three weeks before to three weeks after tasseling and maximum water use from tasseling through the softdough stage (about three weeks after tasseling).**

**PHASE II: TASSELING AND POLLINATION**

**Tasseling occurs about 40-70 days after plant emergence in 90-130 day varieties. The tassel (flower) is thrust out of the leaf whorl about one to two days before it begins shedding pollen. Pollen shed starts two to three days before the i silks emerge from the ear tip and continues for five to eight days. If conditions are favorable, all the silks emerge within three to five days and most are pollinated the first day.**

**Each silk leads to an ovule (a potential kernel). When a pollen grain lands on a silk, it puts out a pollen tube that grows down the silk's center and fertilizes the ovule at the other end in a matter of hours. Shortage of pollen is rarely a problem since about 20,00050,000 pollen grains are produced per silk. Poor ear fill (the number of kernels on an ear) or skipped kernels are**

**nearly always caused by delayed silk emergence or by ovule abortion, both of which are caused by drought, overcrowding or a shortage of nitrogen and phosphorus. Extreme heat (above 35°C) can diminish pollen vigor and also affect ear fill. Some insects like the corn rootworm beetle (Diabrotica spp.) or Japanese beetle (Popillia japonica) can cut off the silks before pollination.**

**Maize is cross-pollinated, and usually 95 percent or more of the kernels of a cob receive their pollen from neighboring maize plants. This also means that different maize types such as the hi-lysine varieties must be kept isolated from other maize pollen if they are to retain their desired characteristics.**

**Pollination is a very critical time during which there is a high demand for both water and nutrients. One to two days of wilting during this period can cut yields by as much as 22 percent and six to eight days of wilting can cut yields by 50 percent.**

**A few days after pollination, the silks begin to wilt and turn brown. Unpollinated silks will remain pale and fresh looking for several weeks but as mentioned above, they can only receive**

**pollen for a week or so after they emerge from the ear tip.**

## PHASE III: FROM KERNEL DEVELOPMENT TO MATURITY

**Most maize ears have 14-20 rows with 40 or more ovules per row and produce about 500-600 actual kernels. Any shortage of water, nutrients, or sunlight during the first few weeks of kernel development usually affects the kernels at the tip of the ear first, making them shrivel or abort. Maize is very prone to moisture stress (water deficiency) at this stage due to a heightened water requirement (up to 10 mm per day under very hot and dry conditions). Wind damage during early kernel development is seldom serious, even though the plants may be knocked almost flat, since they still have the ability to "gooseneck" themselves (curve up) into a nearly vertical position.**

### Stages of Kernel Development in Maize

- **Blister stage: About 10 days after pollination when the kernels begin to swell, but contain liquid with very little solid matter.**

- **Roasting ear stage: About 18-21 days after pollination. Though field maize has a much lower sugar content than sweet maize, at this stage it is still sweet. At this stage the kernels have accumulated only about one-third of the total dry matter yield they will have at physiologic maturity. From this time on, any type of stress is more likely to affect kernel size rather than grain fill at the ear tip.**

- **Dough stage: About 24-28 days after pollination.**

- **Approaching maturity: As maturity nears, the lower leaves begin to turn yellow and die. In a healthy, well nourished plant, this should not occur until the ear is nearly mature. However, any serious stress factordrought, low soil fertility, excessive heat, diseases--can cause serious premature leaf death. Ideally, most of the leaves should still be green when the husks begin to ripen and turn brown. Early death of the maize plant can greatly reduce yields and result in small, shrunken kernels.**

- **Physiologic maturity: About 52-58 days after 75 percent** of the field's ear silks have emerged. The kernels have reached their maximum yield and have ceased accumulating more dry matter. However, they still contain about 3035 percent moisture which is too wet for damage-free combine harvesting (picking and shelling) or for spoilage-free storage (except in the form of husked ears in a narrow crib; see Chapter 7). Small farmers usually let the maize stand in the field unharvested for several weeks or more to allow some further drying. In some areas, particularly Latin America, it is a common practice to bend the ears (or the plants and the ears) downward to prevent rain from entering through the ear tips and causing spoilage. It also helps minimize bird damage and lets in sunlight for any intercropped plants that may be seeded at this time.

**Number of ears per plant: Most tropical and sub-tropical maize varieties commonly produce two to three useful ears per plant under good conditions. In contrast, most U.S. corn belt types are single eared. One advantage of multipleeared varieties (often called prolifics) is that they have some built in buffering capacity**

**in case of adverse conditions and may still be able to produce at least one ear.**

**Grain Sorghum (Sorghum bicolor)**

**Distribution and Importance Although grain sorghum accounted for only 3.6 percent of total world cereal production in 1977 (FAO data), several factors make it an especially important crop in the developing world:**

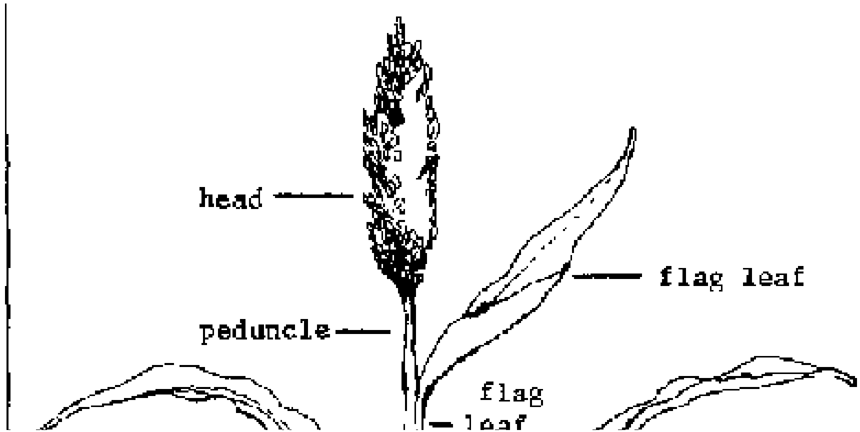
- **The developing nations account for about 60 percent of the world's grain sorghum production.**

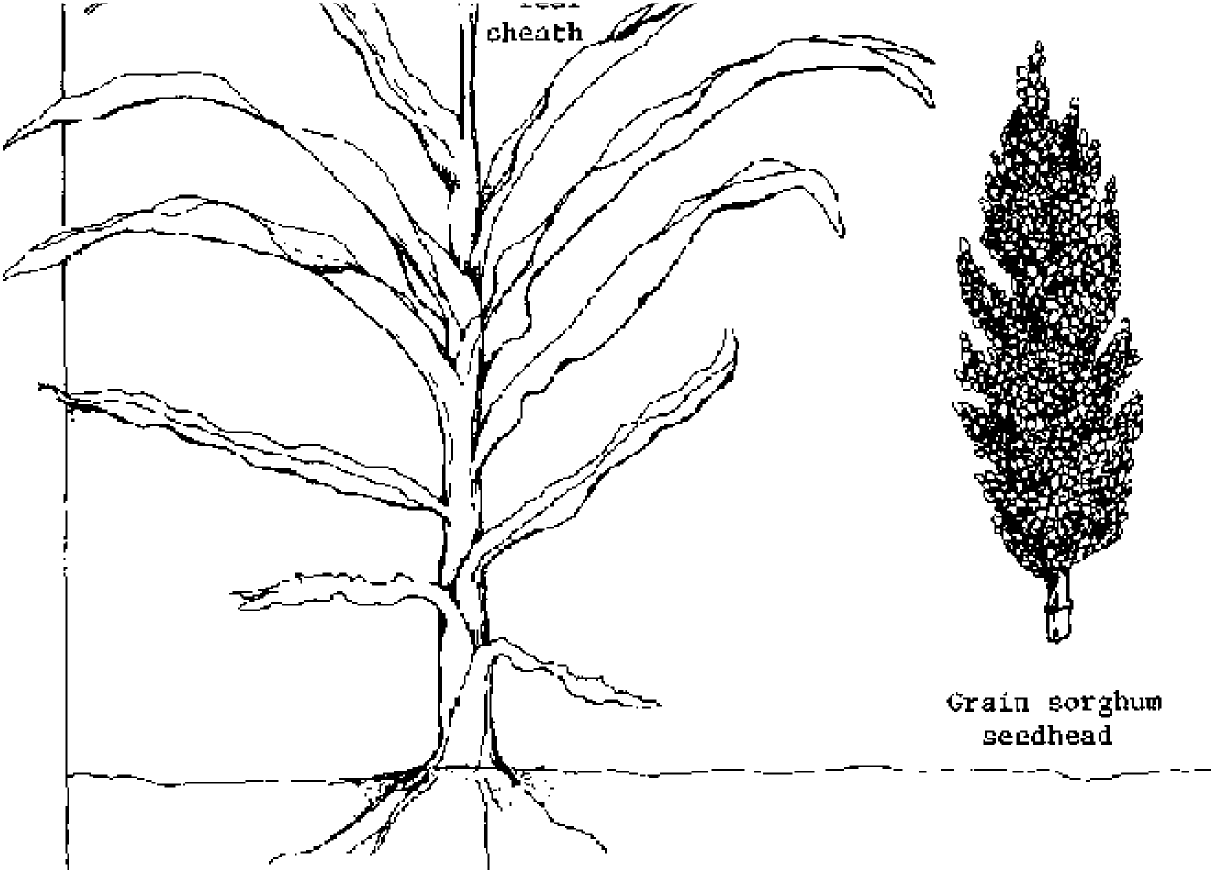
- **It is drought-resistant and heat-tolerant and particularly suited to the marginal rainfall areas of the semiarid tropics (such as the savanna and Sahel zones of Africa where food shortages have been critical).**

**Types of Sorghums**

**Grain Sorghum vs. Forage Sorghum: Where sorghum is grown in the developed world, a definite distinction is made between**

**forage so_ghum and grain sorghum types. For example, in the U.S. (where grain sorghum is often called "milo"), nearly all grain types have had dwarf genes bred into them to reduce plant height to 90-150 cm for more managable machine harvesting, In contrast, forage sorghum types are much taller and have smaller seeds and a higher ratio of stalk and leaves to grain. They are used largely for cattle feed as fresh green chopped forage or silage (green forage preserved by a fermentation process), but are sometimes grazed. Sudangrass is a variety of forage sorghum with especially small seedheads and thinbladed leaves, and sorghumsudan crosses also are available.**






**A grain sorghum plant nearing maturity**

**In the developing countries, especially where cattle are important, most traditional grain sorghum varieties have some forage type characteristics such as tallness and a high proportion of stalk to leaves.**

**There are many regional variations among local grain sorghum types:**

**Yields of Dry Grain**

| | **Lbs./Acre** | **Kg/Hectare** |
|---|---|---|
| Top yields in the U.S. under irrigation | 9000-12,000 | 10,000-13,4000 |
| Top rainfed yields in the U.S. | 5000-8000 | 5600-9000 |
| U.S. Average | 3130 | 3520 |
| Average for the developed countries | 2900 | 3260 |
| Average for developing countries | 400-800 | 450-900 |
| Feasible rainfed yields for farmers using | 3360- | 3000-4500 |

| | | |
|---|---|---|
| improved practices | 5000 | |

**Sweet Sorghum (Sorgo) and Broomcorn: Sorgo types have tall, juicy stalks with a high sugar content and are used for making syrup and also for animal feed in the form of silage and forage. Broomcorn is a sorghum type grown for its brush, which is used mainly for brooms.**

**Sorghum Yields**

**Grain sorghum exhibits greater yield stability over a wider range of cropping conditions than maize. Although it will outyield maize during below-normal rainfall periods, the crop might suffer some damage under very high rainfall. Yields of dry (14 percent moisture) grain are shown under varying growing conditions on page 52 (based on FAO, USDA, and international research institute data).**

**Protein content vs. yield: The protein content of sorghum kernels can vary considerably (7-13 percent on soils low in nitrogen) due to rainfall differences. Since nitrogen (N) is an important constituent of protein, kernel protein content is likely to be**

**highest under very low rainfall that cuts back yields and concentrates the limited amount of N in a smaller amount of grain. Protein fluctuation is much less on soils with adequate nitrogen.**

**Climatic Requirements of Sorghum**

**Grain sorghum tolerates a wide range of climatic and soil conditions.**

**Rainfall: The sorghum plant, aside from being more heat- and drought-resistant than maize, also withstands periodic waterlogging without too much damage.**

**The most extensive areas of grain sorghum cultivation are found where annual rainfall is about 4501,000 mm, although these higher rainfall areas favor the development of fungal seed head molds that attack the exposed sorghum kernels. The more open-headed grain sorghum varieties are less susceptible to head mold.**

**Several factors account for the relatively good drought tolerance**

**of grain sorghum:**

- **Under drought conditions the plants become dormant and will curl up their leaves to reduce water losses due to transpiration (the loss of water through the leaf pores into the air).**

- **The leaves have a waxy coating that further helps to reduce transpiration.**

- **The plants have a low water requirement per unit of dry weight produced and have a very extensive root system.**

**Temperature and Soil Requirements: Although sorghum withstands high temperatures well, there are varieties grown at high elevations that have a good tolerance to cool weather as well. Light frosts may kill the above-ground portion of any sorghum variety, but the plants have the ability to sprout (ratoon) from the crown.**

**Sorghum tends to tolerate very acid soils (down to pH 5.0 or slightly below) better than maize, yet it is also more resistant to**

**salinity (usually confined to soils with pH's over 8.0).**

**Response to Daylength (Photosensitivity)**

**Most traditional sorghum varieties in the developing countries are very photosensitive. In these photosensitive types, flowering is stimulated by a certain critical minimal daylength and will not occur until this has been reached, usually at or near the end of the rainy season. This delayed flowering enables the kernels to develop and mature during drier weather while relying on stored soil moisture. (This is actually a survival feature which allows seed heads to escape fungal growth in humid' rainy conditions.) These local photosensitive varieties usually will not yield as well outside their home areas (especially further north or south) since their heading dates still remain correlated to the rainy season and daylength patterns of their original environment. Despite this apparent adaptation to their own areas, the traditional photosensitive varieties have a relatively low yield potential and may occupy land for a longer period to produce a good yield (due to their fixed flowering dates). In addition there is always the danger that the rains will end early and leave an inadequate**

**reserve of soil moisture for kernel development. Breeding programs are attempting to improve these photosensitive types, and many of the improved varieties show little sensitivity to daylength. Other Sorghum Characteristics Ratooning and Tillering Ability**

**The sorghum plant is a perennial (capable of living more than two years). Most forage sorghums and many grain varieties can produce several cuttings of forage or grain from one planting if not killed by heavy frost or extended dry weather. New stalks sprout from the crown (this is called ratooning) after a harvest.**

*DANGER* The Toxicity Factor: Hydrocyanic Acid

Young sorghum plants or drought-stunted ones under 60 cm tall contain toxic amounts of hydrocyanic acid (HCN or prussic acid). If cattle, sheep or goats are fed on such plants, fatal poisoning may result. Fresh, green forage, silage, and fodder (dried stalks and leaves) are usually safe if over 90-120 cm tall and if growth has not been interrupted. The HCN content of sorghum plants decreases as they grow older and is never a problem with the mature seed. An intravenous injection of 2-3 grams of sodium nitrite in water, followed by 4-6 grams of sodium thiosulfate is the antidote for HCN poisoning in cattle; these dosages are reduced by half for sheep.

**However, ratooning ability has little value in most areas where non-irrigated sorghum is grown. In these areas, either the rainy season or frost-free period is likely to be too short for more than one grain crop or too wet for a mid-rainy season first crop harvest without head mold problems. However, forage sorghums take good advantage of ratooning, since they are harvested well before maturity, usually at the early heading stage. Cattle farmers in El Salvador take three cuttings of forage sorghum for silage-making during the six-month wet season. In irrigated tropical zones with a year-round growing season such as Hawaii, it is possible to harvest three grain crops a year from one sorghum planting by using varieties with good ratooning ability.**

**Some grain sorghum varieties have the ability to produce side shoots that grow grain heads at about the same time as the main stalk (this is called tillering). This enables such varieties to at least partially make up for too thin a stand of plants by producing**

**extra grain heads.**

**Nutritional Value and Uses of Sorghum**

**Nearly all grain sorghum used in the developed world is fed to livestock (mainly poultry and swine). However, in developing countries it is an important staple food grain and is served boiled or steamed in the form of gruel, porridge, or bread. In many areas, it is also used to make a home-brewed beer. In addition, the stalks and leaves are often fed to livestock and used as fuel and fencing or building material.**

**Like the other cereals, grain sorghum is relatively low in protein (8-13 percent) and is more important as an energy source. If eaten along with pulses in the proper amount (usually a 1:2 grain:pulse ratio), it will provide adequate protein quantity and quality. Only those varieties with a yellow endosperm (the starchy main portion of the kernel surrounding the germ) contain vitamin A.**

**Because sorghum is very susceptible to bird damage during**

kernel development and maturity, birdresistant varieties have been developed. Because it has a high tannin content in the seeds, stalks, and leaves, it is partly effective in repelling birds from the maturing seedheads. However, these high tannin varieties are more deficient in the essential amino acid lysine than ordinary varieties which has consequences for humans and other monogastrics like pigs and chickens. In the U.S., this is overcome by adding sythetic lysine to poultry and swine rations that are made from birdresistant sorghum grains. In developing countries a slight increase in pulse intake can overcome this problem in humans.

## Grain Sorghum Growth Stages

Depending on variety and growing temperatures, nonphotosensitive grain sorghum reaches physiologic maturity in 90-130 days within the 0-1000 m zone in the tropics. However, the local, daylength-sensitive varieties may take up to 200 days or more because of delayed flowering. At very high elevations, all varieties may take 200 days or more.

**As with maize, the main difference between a 90-day and 130day sorghum variety is in length of vegetative period (the period from seedling emergence to flowering). The grain filling period (pollination to maturity) is about the same for both (30-50 days). The following sections describe the growth stages and management factors of a typical 95-day variety. These principles remain the same no matter what variety is grown.**

## PHASE I: FROM EMERGENCE TO THREE WEEKS

**Sorghum seedlings will emerge in three to six days in warm, moist soil. Under cool conditions where emergence is delayed, the seeds are especially prone to harmful soil fungi and insects, and a fungicide/ insecticide seed dressing may be particularly beneficial (see Chapter 6). Compared to maize, the small sorghum seeds are low in food reserves which are quickly exhausted before enough leaf area is developed for photosynthesis. For this reason the seedlings get off to a slow start during the first three weeks, after which the growth rate speeds up.**

**This sluggish beginning makes good weed control extra**

**important during this time.**

**For the first 30 days or so, the growing point which produces the leaves and seedhead is below the soil surface. Hail or light frost is unlikely to kill the plant, since new growth can be regenerated by the growing point. However, regrowth at this stage is not as rapid as with maize.**

## PHASE II FROM THREE WEEKS TO HALF-BLOOM (60 days after emergence)

**Growth rate and the intake of nutrients and water accelerates rapidly after the first three weeks. The "flag" leaf (the final leaf produced) becomes visible in the leaf whorl about 40 days after emergence. "Boot" stage is reached at about 50 days when the flower head begins to emerge from the leaf whorl but is still encasea by the flag leaf's sheath. The head's potential size in terms of seed number has by now been determined. Severe moisture shortage at boot stage can prevent the head from emerging completely from the flag leaf sheath. This will prevent complete pollination at flowering time.**

**Half-bloom stage is reached at about 60 days when about half of the plants in a field are in some phase of flowering at their heads. However, an individual sorghum plant flowers from the tip of the head downward over four to nine days, so half-bloom on a per plant basis occurs when flowering has proceeded halfway down the head. Although time to half-bloom varies with variety and climate, it usually encompasses two-thirds of the period from seedling emergence to physiologic maturity. In keeping with the rapid rates of growth and nutrient intake, about 70, 60, and 80 percent of the nitrogen, phosphorus, and potassium requirements (respectively) have been absorbed by the plant by the time of half-bloom. Severe moisture shortage at pollination greatly cuts yields by causing seed ovule abortion and incomplete pollination.**

## PHASE III: FROM HALF-BLOOM TO PHYSIOLOGIC MATURITY (60-95 days)

**The seeds reach the soft dough stage about 10 days after pollination (70 days after emergence) in a 95-day variety, and about half of the final dry weight yield is accumulated during this short period. Hard dough stage is reached in another 15 days (85**

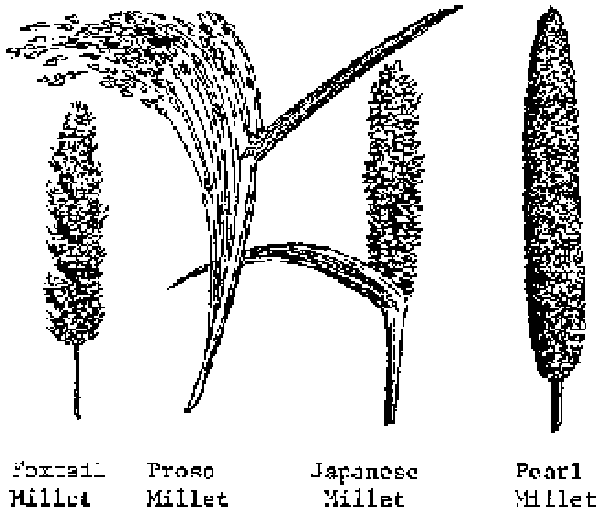
**days after emergence) when about threefourths of the final dry weight grain yield has been attained. Severe moisture stress during this period will produce light, undersized grain. Physiologic maturity is reached in another 10 days (95 days from emergence in the case of this variety.) At this stage, the grain still contains 25-30 percent moisture which is well above the 13-14 percent safe limit for storage in threshed form (after the seeds have been removed from the head). Small scale farmers can cut the heads at this stage and dry them in the sun before threshing or let the heads dry naturally on the plants in the field.**

## The Millets

### TYPES OF MILLET

**The millets comprise a group of small-seeded annual grasses grown for grain and forage. Although of little importance in the developed world, they are the main staple food grain crop in some regions of Africa and Asia and are associated with semi-arid conditions, high temperatures, and sandy soils. Of the six major millet types listed below, pearl millet is the most widely grown**

**and will receive the most emphasis in this manual.**




**Millets - How a sorghum plant develops**

**Pearl Millet**
**Other Names: Bulrush, cattail, and spiked millet, bajra, millet, milt**
**Scientific Name: Pennisetum typhoides, P. glaucum or P. americanum**
**Main Areas of Production: Semi-arid plains of southern Asia**

**(especially India) and the Sahel (sub-Saharan) region of Africa.**
**Important Characteristics: The most drought- and heat-tolerant of the millets; more prone to bird damage than finger millet.**

**Finger Millet**
**Other Names: Birdsfoot millet, eleusine, ragi**
**Scientific Name: Eleusine coracana**
**Main Areas of Production: The southern Sudan, northern Uganda, southern India, the foothills of Malaysia and Sri Lanka**
**Important Characteristics: Unlike other millets, it needs cool weather and higher rainfall; higher in protein than the others.**

**Proso Millet**
**Other Names: Common, French, and hog millet, panicum, miliaceum**
**Scientific Name: Panicum miliaceum**
**Main Area of Production: Central Asia, USSR**
**Important Characteristics: Used mainly as a short-duration emergency crop or irrigated crop.**

**Teff Millet**

**Scientific Name: Eragrostis abyssinica**
**Main Area of Production: Mainly the Ethiopian and East African highlands up to 2700 m where it is an important staple food.**

**Japanese or Barnyard Millet**
**Other Names: Sanwa or shame millet**
**Scientific Name: Echinochloa crusgalli, E. frumentacea**
**Main Areas of Production India, East Asia, parts of Africa; also in the Eastern U.S. as a forage Important Characteristics: Wide adaptation in terms of soils and moisture; takes longer to mature (three to four months total) than the others.**

**Foxtail Millet**
**Scientific Name: Setaria italica**
**Main Area of Production: Near East, mainland China**
**Important Characteristics. Very drought-resistant.**

**Millet Yields**

**Average millet yields in West Africa range from about 300-700 kg/ ha. They tend to be low due to marginal growing conditions**

**and the relative lack of information concerning improved practice. Compared to maize, sorghum, and peanuts, research efforts with millet have only yielded 1000-1500 kg/ha and improved varieties have produced up to 20003500 kg/ha.**

**Climatic Requirements of Millet Rainfall: Pearl millet is the most important cereal grain of the northern savanna and Sahel region of Africa. It is more drought resistant than sorghum and can be grown as far north as the 200-250 mm rainfall belt in the Sahel where varieties of 55-65 days maturity are grown to take advantage of the short rainy season. Although pearl millet uses water more efficiently and yields more than other cereals (including sorghum) under high temperatures, marginal rainfall, sub-optimum soil fertility, and a short rainy season, it does lack sorghum's tolerance to flooding.**

**Soil: Pearl millet withstands soil salinity and alkaline conditions fairly well. (For more information on salinity and alkalinity problems, refer to Peace Corps, Soils, Crops, and Fertilizer Manual, 1980 edition.) It is also less susceptible than sorghum to boring insects and weeds, but shares sorghum's susceptibility to**

**losses from bird feeding, which damages the maturing crop.**

**Nutritional Value and Uses of Millet**

**Pearl, foxtail, and prove millets all contain about 12 to 14 percent protein which is somewhat higher than most other cereals. The most common method of preparing pearl millet in West Africa is as "kus-kus" or "to", a thick paste made by mixing millet flour with boiling water. Millet is used also to make beer. The stalks and leaves are an important livestock forage and also serve as fuel, fencing, and building material. Traditional Pearl Millet Growing Practices in West Africa**

**The traditional West African pearl millet varieties are generally**

**2.5-4.0 m tall with thick stems and a poor harvest index. They are usually planted in clumps about a meter or so apart, very often in combination with one to three of the other reference crops, usually sorghum, cowpeas, and groundnuts. Many seeds are sown per clump, followed by a laborious thinning of the seedlings about two to three weeks later. The tiny millet seeds are low in**

**food reserves which become exhausted before the seedlings can produce enough leaf area for efficient photosynthesis and enough roots for good nutrient intake. Therefore, as with sorghum, the growth rate is very slow for the first few weeks. Two general classes of pearl millet are traditionally grown in West Africa:**

- **The Gero class whose varieties are 1.5-3.0 m tall, early maturing (75-100 days), and neutral or only slightly photosensitive in daylength response. In some parts of the savanna, these short-season Geros mature at the peak of the wet season, but have good resistance to the fungal seedhead molds and insects favored by the rains. The Geros make up about 80 percent of the region's millet and are preferred for their higher yields and shorter maturity over the Maiwa class. They mature in July-August in the Guinea savanna and AugustSeptember in the Sudan savanna.**

- **The Maiwa class is taller (35 m). later maturing (120 - 280 days), and much more photosensitive in daylength response than the Gero group. As with the photosensitive** sorghum varieties, the Maiwas will not flower until at or near the end of the rains, which allows them to escape serious head mold and insect damage. However, they yield less than the Geros and account for only about 20 percent of the region's millet. In the higher rainfall portions of the savanna 500-600 mm per year where both millet and sorghum can be grown, farmers usually prefer to plant photosensitive sorghum varieties. These have about the same length of growing period, but yield more than the Maiwas due to a longer grainfilling period. However, the Maiwas are favored over the sorghums on sandier soils with lower water storage ability. Some farmers will also choose the Maiwas over the sorghums because the former mature slightly sooner, thus spreading out the harvest labor demands for these late season crops. (The Maiwas are harvested a month or so into the dry season.)

Many of the traditional millets produce abundant tillers (side shoots produced from the plant's crown). However, this tillering is non-synchronous, that is, tillering development lags behind that of the main stem. As a result, these secondary shoots mature later than the main stem. If soil moisture remains adequate, two or more smaller harvests can be taken.

Aside from the normal rainfed millet production, the crop is also planted on flood plains or along river borders as the waters begin to recede. This system is referred to as recessional agriculture and also may involve sorghum.

## Peanuts (Arachis hypogea)

### DISTRIBUTION AND IMPORTANCE

Peanuts are an important cash and staple food crop in much of the developing world, particularly in West Africa and the drier regions of India and Latin America. The developing nations account for some 80 percent of total world production, with two-thirds of this concentrated in the semi-arid tropics. Because of repeated droughts, disease problems, and other factors, Africa's share of the world peanut export market declined from 88 percent in 1968 to 43 percent in 1977, while its share of total production fell from 36 percent to 26 percent during the same period.

**Types of Peanuts**

**There are two broad groups of peanuts:**

- **Virginia group: Plants are either of the spreading type with runners or of the bunch (bush) type. Their branches emerge alternately along the stem rather than in opposed pairs. The Virginia varieties take longer to mature (120140 days in the tropics) than the Spanish-Valencia types and are moderately resistant to Cercospora leaf-spot, a fungal disease that can cause high losses in wet weather unless controlled with fungicides (see Chapter 7). The seeds remain dormant (do not sprout) for as long as 200 days after development, which helps prevent premature sprouting if they are kept too long in the ground before harvest.**

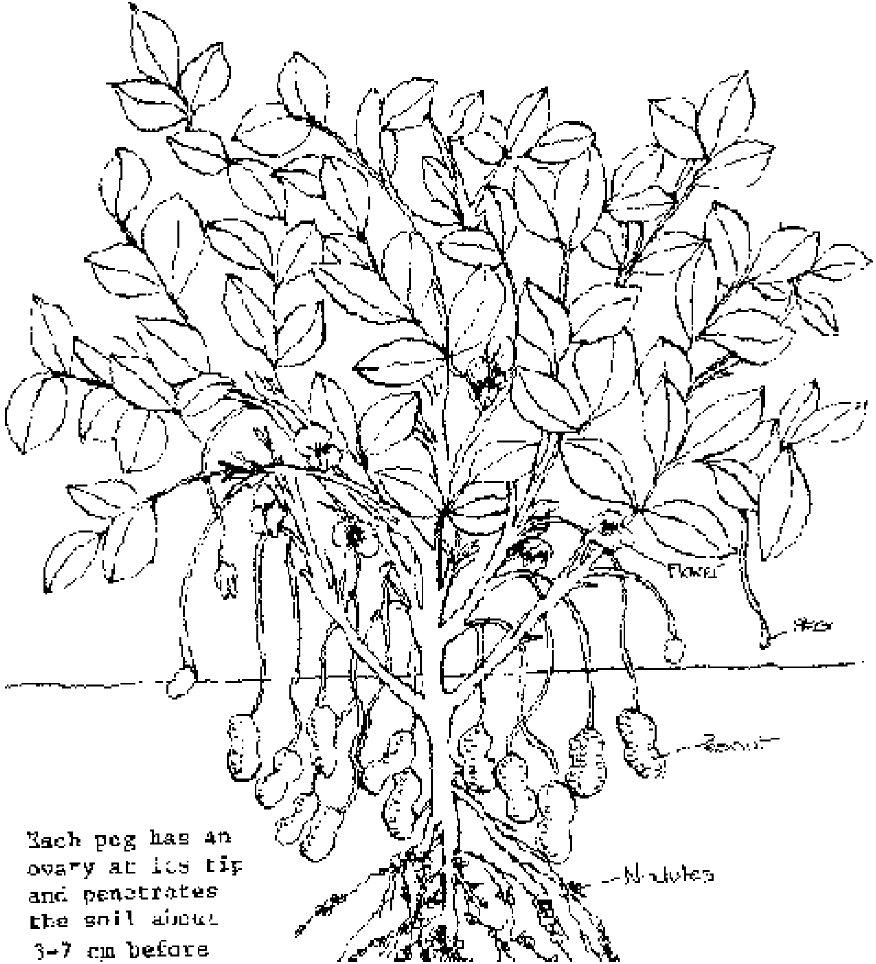
- **Spanish-Valencia group: Plants are of the erect bunch type and non-spreading (no runners). Their branches emerge sequentially (in opposed pairs), and their leaves are lighter green. They have a shorter growing period (90-**

110 days in warm weather), are highly susceptible to Cercospora leafspot, and have little or no seed dormancy. Pre-harvest sprouting can sometimes be a problem under very wet conditions or delayed harvest. They are generally higher yielding than the Virginia variety if leaf spot is controlled.

Plant breeders have made some promising crosses between these two groups.

## Peanut Yields

Average peanut yields in the developing countries range from about 500-900 kg/ha of unselled nuts, compared with the U.S. average of 2700 kg/ha, based on 1977 FAO data. Farmers participating in yield contests have produced over 6000 kg/ha under irrigation, and yields of 4000-5000 kg/ha are common on experiment station plots throughout the world. Feasible yields for small farmers who use a suitable combination of improved practices are in the range of 17003000 kg/ha, depending on rainfall.


Each peg has an
ovary at its tip
and penetrates
the soil about
3-7 cm before


**Peanut plant**

## Climatic and Soil Adaption of Peanuts

**Rainfall: Peanuts have good drought resistance and heat tolerance. They mature in 90-120 days in warm weather, which makes them especially well suited to the short wet season of the northern savanna zone of West Africa. They can be grown in moister climates if diseases (especially leafspot) can be controlled and if planted so that harvest does not coincide with wet weather.**

**Temperature: During the vegetative (leaf development) phase temperature has little effect on yields. However, the rate of flowering and pollen viability are greatly influenced by temperatures during flowering (about 35-50 days after emergence). Pod production is adversely affected by temperatures below 24°C or above 33°C. At 38°C, for example,**

**flowering is profuse, but few pods are produced.**

**Soils: Peanuts do not tolerate waterlogging, so good soil drainage is important. Soils that crust or cake are unsuitable, since penetration of the pegs is unhindered.**

**Clayey soils can produce good results if well drained, but harvest (digging) losses may be high due to nut detachment if the plants are "lifted" when such soils are dry and hard. On the other hand, harvesting the crop on wet, clayey soils may stain the pods and make them unsuitable for the roasting trade.**

**Peanuts grow well in acid soils down to about pH 4.8, but do have an unusually high calcium requirement which is usually met by applying gypsum (calcium sulfate). Peanut fertilizer requirements are covered in Chapter 5.**

## Nutritional Value and Uses of Peanuts

**The mature, shelled nuts contain about 28-32 percent protein and vary from 38-47 percent oil in Virginia types to 47-50 percent oil in Spanish types. They are also a good source of B Vitamins and**

**Vitamin E. Although lower in the essential amino acid lysine (a determinant of protein quality) than the other pulses, peanuts are a valuable source of protein.**

**In the developing nations peanuts are consumed raw, roasted or boiled or used in stews and sauces. The oil is used for cooking and the hulls for fuel, mulching, and improving clayey garden soils.**

**Commercially, the whole nuts are used for roasting or for peanut butter. Alternatively, the oil is extracted using an expeller (pressing) or solvent method and the remaining peanut meal or cake (about 45 percent protein) is used in poultry and swine rations. Peanut oil is the world's second most popular vegetable oil (after soybean oil) and can also be used to make margarine, soap, and lubricants. The hulls have value as hardboard and building-block components.**

## Plant Characteristics of Peanuts

**Peanuts are legumes and can satisfy all or nearly all of their**

nitrogen needs through their symbiotic relationship with a species of Rhizobia bacteria. A characteristic of the peanut plant is that the peanuts themselves develop and mature underground.

**Peanut Stages of Growth**

Depending on variety, peanuts take anywhere from 90-110 days to 120-140 days to mature. The peanut plant will flower about 30-45 days after emergence and will continue flowering for another 30-40 days. The peanuts will then mature about 60 days after flowering.

**PHASE I EMERGENCE**

Within a day or so after planting in warm, moist soils, the radicle (initial root) emerges and may reach 10-15 cm in length within four to five days. About four to seven days after planting, two cotyledons break the soil surface where they will remain while the stem, branches, and leaves begin to form above them. The plants grow slowly in the early stages and are easily overtaken by ,weeds.

**PHASE II - FLOWERING TO POLLINATION**

**Flowering begins at a very slow rate about 30-45 days after plant emergence and is completed within another 30-40 days. The flowers are self-pollinated, but bees and rain improve fertilization (and therefore kernel production) by "triggering" the flowers and aiding in pollen release. The flowers wither just five to six hours after opening. A plant may produce up to 1000 flowers, but only about one out of five to seven actually produces a mature fruit.**

**PHASE III - PEG EMERGENCE TO MATURITY**

**The pegs (stalk-like structures, each containing a future fruit at its tip) begin elongating from the withered flowers about three weeks after pollination and start to penetrate the soil. After the pegs penetrate to a depth of about 2-7 cm, the fruits begin to develop rapidly within about 10 days and reach maturity about 60 days after flowering. Those pegs that form 15 cm ro more above the ground seldom reach the soil and abort.**

**It is important to note that the fruits do not all mature at the**

same time, since flowering occurs over a long period. An individual fruit is mature when the seed coats of the kernels are not fonder wrinkled and the veins on the inside of the shell have turned dark brown. Harvesting cannot be delayed until all the fruits have matured or heavy losses will result from pod detachment from the pegs and from premature sprouting (Spanish-Valencia types only). Choice of harvesting date is an important factor in obtaining good yields.

## Traditional Peanut Growing Practices

Small farmers in some developing countries, especially in West Africa, often plant peanuts together with one or more other crops such as sorghum, millet, cowpeas, cotton, and vegetables. Whether intercropped or sown alone, peanuts are usually planted on ridges (raised up mounds or beds) about one meter apart; this improves soil drainage and facilitates digging, In the northern savanna areas of West Africa, they are generally planted in June and harvested in September or October. In the southern, higher rainfall sections of the savanna, it is often possible to grow two crops (April or May until August for the first, and August or

**September to November or December for the second). Most of the local varieties, especially in the more humid areas, are of the Virginia type which has much better leaf-spot resistance.**

## Common Beans And Cowpeas

### Importance and Distribution

**Along with peanuts, this group makes up the bulk of the edible ,pulses grown in tropical and subtropical developing nations. Aside from their importance as a protein source, the crops play an important role in the farming systems of these areas:**

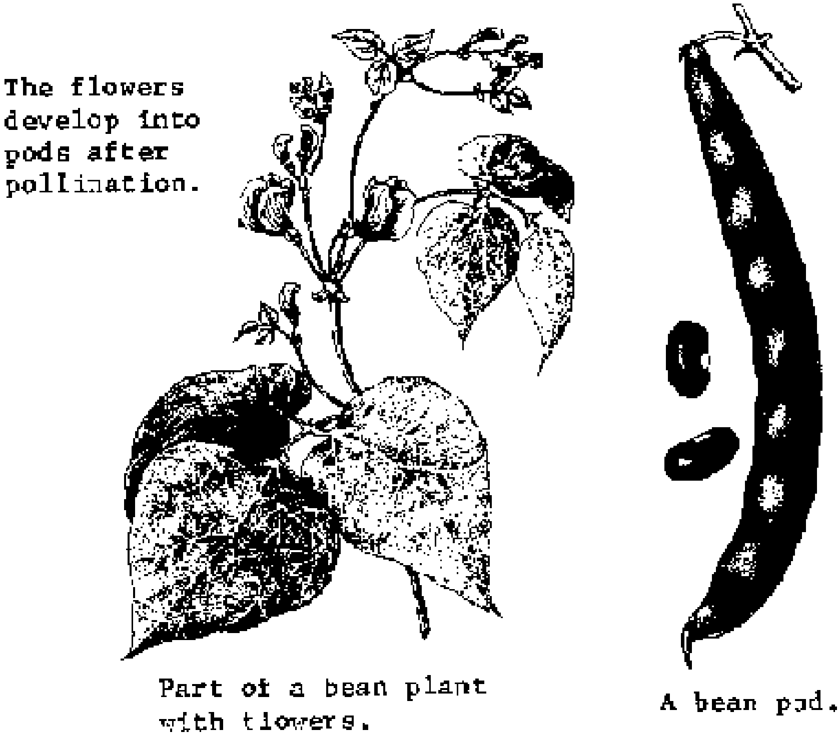
- **They are especially well suited to climates with alternating wet and dry seasons.**
- **Being legumes, they are partly to wholly self-sufficient in meeting their nitrogen requirements.**
- **They are the natural partners of the cereals in intercropping and crop rotations (see Chapter 4).**

**According to FAO estimates for the 1975-77 period, world dry bean production was about 12.4 million tons annually. Latin America accounts for about a third of world production and produces mainly common (kidney) beans which are also the major type grown in East Africa. Cowpeas are the major grain legume (peanuts excluded) of the West Africa savanna zone.**

**This section deals with common beans and cowpeas (dry beans). In the appendices are similar descriptions of other pulses such as pidgeonpeas, chickpeas, lima beans, mung beans, soybeans, and winged beans.**

**Common (Kidney) Beans (Phaseolus vulgaris)**

**Other Names: Field beans, frijoles, haricot beans, string beans (immature stage), snap beans (immature stage).**




**Bean plant and pod**

## Types

**Bean varieties can be classified according to three basic**

**characteristics - seed color, growth habit, and length of growing period:**

**1. Seed Color: Most are black or red seeded, and there are usually distinct local preferences regarding color.**

**2. Growth Habit: Varieties can be erect bush, semi-vining or vining types; the latter have a vigorous climbing ability and require staking or a companion support crop like maize. Bush varieties flower over a short period with no further stem and leaf production afterwards; these are called determinate. The vining types flower over a longer period and continue leaf and stem production; these are called indeterminate. Semi-vining varieties can be of either type. Given their longer flowering period, most indeterminates have uneven pod maturity with the harvest period stretched out over a number of weeks.**

**3. Growth Period: In warm weather, early varieties can produce mature pods in about 70 days from plant emergence, while medium and late varieties take 90 days or more. Time to first flowering ranges between 30 and 55 days. With some exceptions,**

**the erect busy types reach maturity earlier than the vining indeterminate types. Plant breeders are developing indeterminate varieties with shorter growing periods and more compact maturity.**

**Climatic Requirements of Beans Rainfall: Common beans are not well suited to very high rainfall areas (such as the humid rainforest zones of tropical Africa) because of increased disease and insect problems. Ideally, planting should be timed so that the latter stages of growth and harvest occur during reasonably dry weather.**

**Temperature: Compared to sorghum and millet, beans do not tolerate extreme heat or moisture stress well. Few varieties are adapted to daily mean temperatures (average of daily high and low) over 28 C or below 14 C. Optimum temperatures for flowering and pod set is a daytime high of 29.5°C and a nighttime low of 21 C. Blossom drop becomes serious over 36 C and is aggravated also by heavy downpours.**

**Soil: The plants are very susceptible to fungal root rot diseases,**

**and good drainage is very important. They usually grow poorly in acid soils much below pH 5.6, since they are especially sensitive to the high levels of soluble manganese and aluminum which often occur at the lower pH levels.**

**Daylength: Unlike some sorghums and millets, most beans types show little response to daylength variations.**

**Nutritional Value and Uses of Beans**

**Common beans contain about 22 percent protein on a dry seed basis. They provide adequate protein quality and quantity for older children and adults if eaten in the proper proportion with cereals (about a 2:1 grain:pulse ratio. In the green bean form, they provide little protein, but are a good source of Vitamin A. The leaves can be eaten like spinach and also are used as livestock forage.**

**Cowpeas ( Vigna sinensis, V. unguiculata, V. sesquipedalia)**

**Other Names: Black-eyed peas, southern peas, crowder peas.**

## Types

**Cowpeas have much the same variations in seed color, growth habit, and length of growing period as common beans except that cowpea seeds are usually brown or white. There are three separate species:**

- **Vigna Sinensis: the common cowpea in Africa and most of Latin America. The large, white seeded types are preferred in most of West Africa.**

- **Vigna unguiculata: catjung cowpea, a primitive type found mainly in Asia, but also in Africa.**

- **Vigna sesquipedalia: the asparagus or yardlong bean widely grown in Asia mainly for its immature pods.**

**Most traditional varieties tend to be late maturing (up to five months' and vining Improved bush (little or no vining) types are available and capable of producing good yields in 80-90 days.**

## Growing Practices and Yields of Cowpeas

**Traditional practices and yield constraints of cowpeas are similar to those of common beans. Average yields in the developing countries run from 400-700 kg/ha of dry seed, compared to a California (U.S.) average of about 2200 kg/ha under irrigation. Field trial yields in Africa and Latin America are largely in the 1500-2000 kg/ha range with some over 3000 kg/ha.**

## CLIMATIC REQUIREMENTS OF COWPEAS

**Rainfall: Cowpeas are the major grain legume (peanuts excluded) of the West African savanna (zone). However, they also are grown in many other regions. They have better heat and drought tolerance than common beans, but the dry seed does not store as well and is very susceptible to attacks by weevils (see Chapter 7).**

**Temperature:**

**High daytime temperatures have little effect on vegetative growth but will reduce yields if they occur after flowering. High temperatures at this time can cause the leaves to senesce (die off) more quickly, shortening the length of the podfilling period.**

**High temperatures will also increase the amount of blossom drop. As with common beans and most crops, humid, rainy weather increases disease and insect problems. Dry weather is needed during the final stages of growth and harvest to minimize pod rots and other diseases.**

**Soil: Cowpeas grow well on a wide variety of soils (if they are well drained) and are more tolerant of soil acidity than common beans.**

**Nutritional Value and Uses of Cowpeas**

**The dry seeds contain about 22-24 percent protein. The immature seeds and green pods also are eaten. They are considerably lower in protein than the mature seeds, but are an excellent source of Vitamin A while green, as are the young shoots and leaves. The plants are a good livestock forage and are sometimes grown as a green manure and cover crop (see Chapter 5).**

**Increasing reference crop production**

**There are basically four ways of increasing the production of the**

**reference crops:**

- **Improving existing cropland**
- **Extending cultivation to new, uncropped areas**
- **Improving the infrastructure**
- **Establishing crop improvement programs.**

**Any meaningful production increase will require varying emphasis on all four methods.**

**Improving Existing Cropland**

**Unquestionably, improved drainage (by land leveling, runoff canals or underground tile drains) and erosion control are high-gain investments. Erosion control not only reduces soil losses and yield deterioration, but in many cases actually improves production by increasing the amount of rainfall retained by the soil.**

**In the case of irrigation projects, however, the results are often mixed. Many irrigation projects have paid little attention to the potential environmental damage or to the technical problems and**

**soil types involved. Huge dams and artificial lakes have definite appeal on paper, but have often led to drainage and salt accumulation problems, as well as to weed-choked canals and serious health hazards like malaria and schistosomiasis (bilharsia).**

**Pumping projects relying on wells face similar problems and can seriously lower the water table to the point of endangering the supply. Water alone is not enough to assure profitable yields which must be high to cover the added costs of irrigation. Unless such projects are carefully planned and combined with a crop improvement program, the results are likely to be disappointing.**

## Extending Cultivation To New Areas

**The FAO estimates that total world food production increased by about 50 percent from 1963-76, while cultivated land area grew by only two percent. Estimates concerning the amount of additional cultivable land differ considerably, but suggest that the world as a whole is utilizing only about onethird to one-half of actual and potential arable land (suitable for crops or for**

**livestock). The largest areas of "new" land are in the lowland tropics of Latin America, Africa, and Southeast Asia. There are, however some drawbacks:**

- **Only a small percentage of these lands are capable of sustaining intensive agriculture because of soil or climate factors; an alarming proportion has been claimed by land speculators or is being divided up into ranches by investors, as in Brazil.**

- **Whether in high rainfall or in arid regions, much of this land is prone to accelerated erosion or irrigation-induced salinization (accumulation of salts at the soil surface).**

- **As we have seen, most of the reference crops are not well adapted to high rainfall and humidity. Pasture and perennial crops may be the best choices under these constraints.**

## Improving the Infrastructure

**In agriculture, the infrastructure refers to those installations,**

**facilities, inputs, and services that encourage production. The most important of these are:**

- **Roads and transport**
- **Markets and marketing standards**
- **Storage facilities**
- **Improvements to land such as drainage, erosion control, and irrigation**
- **Yield-increasing technology**
- **A viable extension service**
- **Availability of agricultural machinery and equipment**
- **Political stability**
- **Credit**
- **An equitable land tenure and distribution system**
- **National planning for agricultural development**
- **Crop prices that encourage increased output**

**The small farmers in most areas of the developing world do not enjoy the same access that larger farmers do to these essential factors of production. Agricultural public works projects such as**

**irrigation, flood control, and farm-to-market roads are usually undertaken according to pure economic feasibility or in response to special interest groups. Larger farmers in a number of developing countries, especially in Latin America, are often organized into producer's associations with very effective lobbying powers.**

**Inequities in land tenure and distribution can have tremendous social and economic consequences and can effectively dampen farming incentives for those affected. In El Salvador, 19 percent of the farms occupy about 48 percent of the land and belong to wealthy "latifundistas" (ranch-type farmers) who grow cotton, coffee, and sugarcane, frequently on an absentee basis. These farms are concentrated on the country's best soil, while the "campesinos" (small farmers) are restricted to the eroded and rocky hillsides where they grow maize, sorghum, and beans. About 47 percent of the country's farms are smaller than 2.47 acres (one hectare) and occupy only four percent of the total land. The majority of the farm units in El Salvador, Guatemala, and Peru have been designated as sub-family.**

**While the implementation of most other infrastructural essentials is hindered mainly by insufficient capital, land reform faces heavy political obstacles and in some cases is not feasible in terms of land supplies. Furthermore, when small farmers purchase land in densely populated regions like the Guatemala Highlands, the Cibao area of the Dominican Republic, and the lake region of Bolivia, competition frequently drives land prices too high for farming to be economical.**

## Crop Improvement Programs

**More than any other single factor, the development of yieldimproving technology associated with the crop improvement programs of the national and international research institutes will play the mayor role in increasing the yields of the reference crops in the developing countries.**

## Reference crop improvement programs

**The term "crop improvement" is a broad one and refers to any attempt to improve crop yields, quality, palatability or other**

**characteristics through plant breeding or the development of improved growing, harvest, and storage practices. The most successful efforts are well-organized, multidisciplinary (involving several relevant skill areas such as entomology and soil fertility), and crop-specific and aim at developing a "package" of improved practices centered around highyielding, adapted varieties.**

**A large number of yield-determining factors and crop characteristics can be at least partially manipulated or controlled by plant breeding and improved production practices' as shown in the table on the next page.**

**Farming Practices Affecting Crop Yields and/or Quality**

- **Method of land preparation (type of tillage and seedbed)**
- **Fertilizer use (kind, amount, timing, placement)**
- **Variety selection Plant density and spacing**
- **Water management (soil drainage, erosion control, moisture conservation practices)**

- **Control of weeds, insects, diseases, nematodes, and birds by chemical or nonchemical methods Adjustment of soil pH**

- **Control of soil compaction due to equipment or animals**

- **Cropping system (monoculture yersus intercropping; crop rotation)**

- **Harvesting, drying, and storage methods**

**Non-manipulative factors:**

**In contrast to the production factors listed above there are a number of others largely beyond the control of both the farmer and the crop improvement worker. These include such variables as the weather and certain soil characteristics (i.e. texture, depth, filth).**

## Crop improvement programs for individual crops

## Maize

## Potential for Improvement

**Of all the reference crops, maize has the highest yield poten tial in terms of grain production per unit of land area under conditions of adequate moisture and improved practices. Maize is generally less troubled by insects and diseases than the pulses, especially beans and cowpeas. In addition, more breeding work has been done with maize than any other major food crop.**

| | Good | Fair to Good | Fair | Poor to Fair | Poor to Good | Poor |
|---|---|---|---|---|---|---|
| Crops in General | Harvest index (ratio of stalk and leaves to grain)<br>Plant ar-chitecture (height, leaf size, leaf weight, etc.) | General plant vigor and yield ability<br>Length of growing period<br>Fertilizer response<br>Plant density tolerance | | Resistance to insects<br>Resistance to nematodes<br>Resistance to heat and cold<br>Tolerance to low or high pH<br>Tolerance to low phospho-rous | Resistance to diseases<br>Resistance to droughts<br>Nutritional value<br>Palatability & cooking quality | |
| The Ref-erence | | | | | | |

| Crops | | | | | | |
|---|---|---|---|---|---|---|
| Maize | | Husk covering<br>Resistance to tipping over<br>Ears/plant | | | | |
| Sorghum/Millet | | Photosensitivity<br>Tillering<br>Vitamin A (sorghum) | Ratooning ability<br>Bird resistance (sorghum) | Resistance to striga weed<br>Resistance to head mold (sorghum) | | Resistance to birds (millet) |
| Peanuts | | Resistance to leaf spot<br>Seed dormancy | | Resistance to nematodes<br>Susceptibility to aflatoxin | | |
| Beans and Cowpeas | Growth habit (vining or bush) | Seedcoat color | | | Resistance to disease and insects | |

## Success of control attained by plant breeding and improved crop production - Control Attained

## Current Research Activities and Crop Programs

The International Maize and Wheat Improvement Center (CIMMYT)* in Mexico is the institute most involved in maize improvement and acts as the caretaker and shipping agent for the world's most complete collection of maize germplasm (plant genetic material). It cooperates extensively with the International Institute for Tropical Agriculture (IITA) in Nigeria and The International Center for Tropical Agriculture in Columbia (CIAT) in their respective maize programs as well as with national improvement programs throughout the developing world. In 1979, CIMMYT sponsored international maize variety trials in 84 countries at 626 sites to compare its varieties with those from local and other foreign sources.

The CIMMYT-developed varieties originate from a well-organized breeding program. During the 1970s the center developed 34 germ plasm pools (genetic groups) classified according to three climate types (tropical lowland, tropical highland, and temperate), four grain types (flint, dent, white, yellow), and three lengths of maturity (early, medium, late). Advanced lines are

**developed from these pools by selecting for yield, uniformity, height, maturity, and resistance to diseases, insects, and lodging (tipping over). They are then grown at a number of locations in Mexico. The most promising are used in preliminary international trials, and the best of these become experimental varieties for more extensive trial work overseas.**

**Spreading Improvement Practices for Maize**

**From 1961-77, total maize production in the developing countries rose by 66 percent, while acreage increased by 33 percent and yields by 24 percent. However, on an individual country basis, only about half the developing countries have made significant gains (1979 CIMMYT Annual Report). The bulk of adaptive research work with maize in the developing countries has occurred in certain areas of Latin America. Africa and Asia, however, have location-specific growing problems in terms of soils, climate, insects, and diseases for which varieties and improved practices still must be developed. The CIMMYT is presently cooperating with national maize programs in Tanzania, Zaire, Ghana, Egypt and Pakistan as well as Guatemala and is**

**providing staff support to most of them. In addition, it cooperates on a regional basis with Central America and the Caribbean, South and Southeast Asia (11 countries), and the Andean zone (Bolivia, Colombia, Ecuador, Peru, and Venezuela all grain importing countries).**

**Disease and insect resistance is a top priority at CIMMYT. This organization has a cooperative breeding program with six national maize programs (Thailand, the Philippines, Tanzania, Zaire, Nicaragua, and El Salvador) to develop resistance to downy mildew (important in Asia and spreading to other regions), maize streak virus (Africa), and corn stunt virus (tropical Latin America).**

**Maize Production Achievements**

**The Puebla Project in Mexico was the first large-scale attempt to improve small-farmer maize production.**

**Under CIMMYT administration, the project involved 47,000 farm families in a highland region of Puebla State. Average farm size in**

**the project area was 2.7 ha, operating mainly under dryland (non-irrigated) conditions. Several "packages" of improved practices were developed to suit varying climatic and soil conditions in the zone, and adequate support and delivery systems were sought for the needed inputs, including agricultural credit. By 1972, maize production had increased in the project area by some 30 percent and average family income had increased by 24 percent in real terms. Rural employment was also favorably affected due to an increase in labor needed for every hectare of maize.**

**The Puebla Project was innovative in moving the "Green Revolution" (the first organized attempt to develop yield improving practices for staple food crops in developing countries) off the experiment station and into the field and in concentrating on dryland rather than irrigated farming.**

**Similar examples exist in many other developing countries. Experimental plots frequently yield over 6000 kg/ha and it is generally agreed that 3000 kg/ha or more is a reasonable yield goal for small farmers in most regions. Since the real test of an**

**improved variety is its performance under actual farm conditions, CIMMYT is encouraging the cooperating countries to run extensive trials on farmers' fields rather than confining them to the experiment station where conditions are often unrealistically ideal. On the Horizon: Scientists have been working on breeding a nitrogenfixing ability similar to that of legumes into maize. By 1985, they hope to have experimental varieties capable of satisfying up to 10 percent of their nitrogen requirements.**

## Grain Sorghum

### Potential for Improvement

**Yields of grain sorghum are generally not as spectacular as those of maize, since the crop is often grown under less than ideal conditions. Sorghum's advantage over maize is its much better yield stability over a wider range of climatic conditions, especially under high temperature and low rainfall. Many of the traditional varieties in the semi-arid tropics are overly tall, are photosensitive, and have an excessive ratio of stalk and leaves to grain. Their delayed flowering enables them to escape serious**

**grain head mold problems and insect damage, but often there is too little soil moisture for grain development which takes place at the start of the dry season. These factors, along with poor management and the large plants' intolerance to healthy plant densities (populations), account for low yields averaging around 600-900 kg/ha in the semi-arid tropics.**

**Current Research Activities and Crop Programs**

**The International Crops Research Institute for the Semiarid Tropics (ICRISAT), located in Andhra Pradesh, India, is the major international institute engaged in sorghum improvement. Some of its major goals include the development of varieties with little or no photosensitivity. These varieties would have a shorter growing season and be better adapted for drier areas or shallow soils with low water holding capacity. They would be planted later, but flower about two weeks earlier than traditional types and therefore need good head mold resistance for maturing under more humid conditions. Plant height would be about 2.0-2.5 meters with a better ratio of grain to stalk and leaves. Since sorghum plants are an important livestock forage in much of the**

**semiarid tropics dwarf varieties like those used in the U.S. would not be acceptable. The new varieties would mature in 90-120 days.**

**Also under consideration are plants with heavy tillering ability to allow compensation for low plant populations and a variety with resistance to striga (a serious parasitic weed, see Chapter 6), sorghum midge, sorghum shoot fly (see Chapter 6) and drought. Work is also being done to develop more coldtolerant varieties for highland or cool-season tropical conditions, and plants with improved disease resistance, especially to downy mildew, charcoal rot, smuts, anthracnose, and rust 'see Chapter 6). Finally, the institute hopes to develop a hi-lysine and higher protein sorghum that has better cooking quality and palatability.**

## Spreading Improvement Practices for Sorghum

**In the southern savanna region of West Africa, improved photosensitive varieties have yielded over 3500 kg/ha in 120-140 days, some two months less than local varieties. They can be sown later in the wet season and will flower about 8-14 days**

**earlier than the local types, thus assuring better moisture availability for grain filling.**

**As of yet, highly photoinsensitive (day neutral) varieties with good head mold resistance hay e not been developed. There are improved types of this class that are available with 90-120 day maturities, but their planting must be scheduled late enough in the wet season so that the grain fill period occurs at the start of the dry season to avoid head mold. This, however, subjects them to probable moisture stress**

**Improvements in sorghum protein: In 1974 two lines of sorghum with 30 percent more protein and double the lysine of conventional types were discovered in Ethiopia. However, these lines suffer from some of the same drawbacks as hi-lysine maize in that the grain has a soft starch, floury endosperm (the major portion of the seed surrounding the germ Lembryol) that is very susceptible to storage insects and to breakage under grain threshing using animal trampling. Also, studies have shown these extra protein benefits to vary greatly under different environmental conditions. For example, low soil nitrogen content**

**can cause both the lysine and protein percentage to drop to normal levels. It may be 1985 or later before such improved nutrition varieties are released.**

**Nitrogen-fixing ability: As with maize, attempts to breed some nitrogen-fixing ability into sorghum are only in the early experimental stages.**

**Production improvements and the future: Sorghum lags behind maize in successful on-farm yield improvement campaigns. Most successes have occurred in the less marginal rainfall areas. For example, although high-yielding sorghum varieties were released in India in the mid-60's, they spread little beyond regions with assured rainfall or irrigation. A mayor factor is the highly variable climatic environment of the semi-arid topics where standardized technology packages have only limited suitability, thus requiring greater adaptive research efforts. However, organized efforts at sorghum improvement are much more recent than those for maize, and the future does look promising.**

## Millet

## Potential for Improvement

**Millet yields are generally lower than those of sorghum due to harsher growing conditions and a shorter period of grain filling. Traditional West African varieties have major limiting factors such as poor plant architecture. They tend to be overly tall and have a poor harvest index.) In addition, the photosensitive types often flower too late in the season, causing moisture stress during grain filling. Those varieties which are not as affected by daylength (the Geros) have moderate tillering ability, but it is not synchronous with the main stem. Thus, most of the tillers flower too late, when moisture is not adequate for grain filling.**

## Current Research Activities and Crop Problems

**The ICRISAT breeding program concentrates mostly on pearl millet, and it aims at improved drought, insect, and disease resistance, increased response to improved practices, better harvest index, and varieties with a range of maturities to suit varying rainfall patterns. It is selecting also for varieties particularly suited to intercropping combinations. Protein content**

**and early seedling vigor are other concerns.**

**In West Africa and the Sudan ICRISAT has a program to develop high-yielding sorghum and millet varieties. This cooperative program includes the countries of Mali, Upper Volta, Niger, Ghana, Chad, The Gambia, Senegal, Nigeria, Mauritania, Cameroon, and Benin.**

**Achievements in Millet Improvement**

**As with sorghum , millet improvement efforts in the developing countries are relatively recent and at an early stage. The ICRISAT trials in West Africa during 1976 and 1977 showed that new varieties were not much better than the existing West African types with a few exceptions. The major problem was lack of disease resistance and overly early maturity. On the other hand, breeding efforts in Senegal have produced high-yielding dwarf types capable of better fertilizer response. These have an improved harvest index and a maturity range of 75-100 days. Some of the best ICRISAT varieties have yielded up to 4000 kg/ha in international trials. Progress also is being made in the**

**development of varieties with good resistance to downy mildew (Sclerospora graminicola), a serious fungus disease encouraged by high humidity. As with maize and sorghum, attempts are being made to develop some limited nitrogen-fixing ability in millet, but results are at least four to five years away.**

**On the Horizon: Millet production should expand significantly in the future as more marginal rainfall land is brought under cultivation. Further research is expected to make the millets one of the most productive cereals on a yield per area per time basis (yield of crop in a certain area per cropping cycle per year).**

## Peanuts

### Potential for Improvement

**When grown under ideal moisture conditions, peanut and other pulse crop yields are about one-third to one-half those of maize. However, since peanuts are about three times higher in protein than maize, the yields are actually very similar on a protein per area basis (a 2000 kg/ha peanut crop produces about the same**

**total amount of protein as a 6000 kg/ha maize crop). This is also the case with the other pulses, all of which have two to three times more protein than the cereals. In short, the pulses are geared more to producing modest yields of high protein seed rather than high yields of starchy seed as with the cereals. Although the lower yields of the pulses should be kept in mind, there is potential for yield improvement in the developing countries where production per hectare lags considerably behind that of the developed countries.**

**Research Activities and Crop Improvement**

**Since peanuts are selfpollinated, the development of new varieties by crossing is difficult and time-consuming. The individual flowers must be manually emasculated and then hand pollinated. Since seed production per plant is comparatively low, multiplication of improved types is very slow, although they can be propagated by cuttings.**

**Most efforts concentrate on collecting and improving local and introduced varieties by selecting for adaptability, drought**

**resistance, oil and protein content, disease and insect resistance, and shelling percentage (ratio of shell weight to kernel weight).**

**Spreading Peanut Improvement Activities**

**The major international institute involved with peanut improvement in the developing countries is ICRISAT. Advanced work is also being done in several of the developed countries such as the U.S. (especially Georgia, North Carolina, and Texas), Australia, and South Africa, but it is designed to serve their local conditions. Other centers of peanut improvement are Senegal, Nigeria, the Sudan, Mexico, Argentina, and Brazil.**

**Breeding for earliness to suit short rainy seasons, seed dormancy (to prevent in-ground sprouting), and resistance to rust, leaf spot, and aflatoxin (see Chapter 6) are all being conducted by ICRISAT. Work in Senegal has developed several lines resistant to rosette virus, a serious problem in the wetter peanut zones of Africa.**

**Of the reference crops, peanuts are the most complicated in**

**terms of growing and harvesting practices needed for good yields. Seed bed preparation, weed and disease control, and harvesting require particular attention to detail and timeliness. Being a much higher value crop than the cereals, repeated applications of foliar fungicides for leaf spot control have a good cost-benefit ratio and are another example of the relative sophistication required for good yields. Undoubtedly, plant breeding has a role to play in peanut improvement, but improved management practices are particularly important for boosting yields.**

**In those developing countries where peanuts are a major export crop, marketing is usually controlled by a government board, which also provides storage facilities and may act as a supplier of seed, fertilizer and other inputs. Under these condicions, adaptive research work is also given greater priority, but the weak link is also the extension system, which must bridge the gap between the farmer and the experiment station. In general, yields are far below the 1700-300 kg/ha range that is feasible under improved practices where moisture stress is not serious.**

**Beans and Cowpeas**

**Until the early 1970s, pulse improvement had been largely neglected. Compared to the cereals, these grain legumes seemed to offer less promising opportunities due to their relatively low yields and greater susceptiblity to insects and diseases. However, in view of their high protein contents and potential as nutritional complements to the cereals, research and extension programs can no longer afford to ignore them. The best yields of the cereals and the pulses are fairly similar when compared on a protein produced per area basis.**

**Common Beans**
**Potential for Improvement**

**Early research seemed to suggest that common beans were one of the least productive of the pulses. However, a comparative growth study by the International Center for Tropical Agriculture (CIAT) in 1978 involving five grain legumes showed that common beans and cowpeas were the two most efficient on a yield per day of growth basis (the other three involved were pigeon-peas,**

**soybeans, and mung beans).**

**Unfortunately, current average yield for Africa and Latin America are a low 600 kg/ha, while CIAT has obtained up to 4300 kg/ha under monocropping (beans as the sole crop) and 3000 kg/ha in mixed plantings with maize.**

**Current Research Activities and Crop Programs**

**The major international institute involved in common bean improvement is CIAT. In 1973 they established a Bean Production Systems Program to increase the production and consumption of the crop in Latin America. In addition it also cooperates with developing countries in other areas. This effort is now being supplemented by a recently organized U.S. government-sponsored program for cooperative dry bean research between U.S. universities and developing countries.**

**The CIAT program aims to increase bean yields through several methods:**

- **Development of improved varieties resistant to major**

**diseases and several stress factors like low soil phosphorus, soil acidity, drought, and temperature extremes. Special attention is being given to mixed cropping with maize.**

- **Breeding for improved nitrogen fixation. Currently, common beans are one of the more inefficient nitrogen fixers and require moderate rates of supplemental fertilizer.**

- **Developing improved management practices for both monoculture and mixed cropping systems (see chapter 4).**

- **Training personnel from national programs in other developing countries and developing a strong bean research network in Latin America and East Africa.**

**As part of its international trials program, CIAT maintains an International Bean Yield and Adaptation Nursery (IBYAN), consisting of 100 entries. This IBYAN is replicated by CIAT and shipped to many other countries to be used in their experimental**

**work with beans. The Center for Tropical Agriculture, Research, and Training (CATIE) in Turrialba, Costa Rica also is involved in bean improvement work.**

**Spreading Bean Improvement Practices**

**After nearly some five years of breeding work, most of the improved varieties CIAT sent out for international trials in 1979 carried some resistance to major pest problems like common mosaic virus, rust, common bacterial blight, angular leaf spot, anthracnose, and a damaging species of leafhopper (Empoasca Kraemeri) prevalent in Latin America. Strains were found also that showed some tolerance to low levels of soil phosphorus and to aluminum and manganese toxicity which often affects bean in highly acidic soil (much below pH 5.5). Both CIAT and CATIE have made significant progress in improving bean-maize multiple cropping systems through improved management and bean variety development.**

**Due to the relatively recent interest in bean research, on-farm yield improvement programs have made nowhere near the**

**impressive and widespread gains of maize, rice, and wheat. However, research achievements in breeding and management are at the point where farmers can increase their yields with a well-organized extension program.**

**Cowpeas**

**Progress in Cowpea Improvement**

**The International Institute for Tropical Agriculture (IITA) in Nigeria is the mayor international institute involved in cowpea improvement and is working toward good pest resistance, improved yields, and the development of a package of improved practices for cowpeas under multiple cropping conditions common in tropical Africa. By 1978, IITA had released a total of five new strains (VITA 1-5) with better yield and pest resistance and a good protein content. They are capable of producing 1500-2500 kg/ha under small-farmer improved management, compared to the current West African average of around 500 kg/ha. The creamy white seed color of VITA 5 is favored in much of Africa. As with common beans, on-farm yield improvement**

**extension efforts are still in their early stages.**

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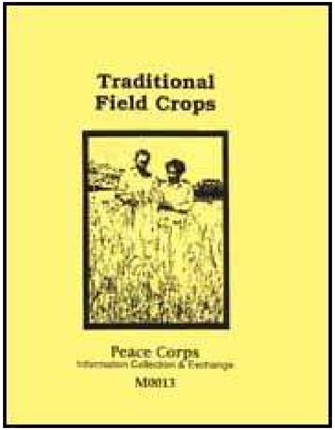





## Traditional Field Crops (Peace Corps, 1981, 283 p.)

## Planning and preparation

**This chapter deals with reference crop production fundamentals and current recommendations concerning cropping systems, land preparation, seed selection, and planting. The production fundamentals section describes the how, what, and why of these farm operations. The compendium section provides a current summary of reference crop production recommendations based largely on information from international research institutes and some national extension services. Although the compendium section does offer general suggestions for the various crops, agriculture is a location-specific endeavor. This section is mainly designed to show how recommendations vary according to differences in each area's physical environment and specific infrastructure.**

### Cropping systems

**As explained earlier, the term "cropping system" refers both to a farmer's or region's overall cropping pattern, and to the specific crop sequences and associations involved, namely:**

**1. Monoculture: The repetitive growing of a single crop on the same field year after year.**

**2. Crop Rotation: The repetitive growing of an orderly succession of crops (or crops alternating with fallow) on the same field.**

**3. Multiple Cropping:**

**a. Sequential cropping: Growing two or more crops in succession on the same field per year or per growing season, sometimes referred to as double or triple cropping. Example: Planting maize in May, harvesting it in August, and then planting beans. Only one crop occupies the field at a time.**

**b. Intercropping: This is the most common definition of multiple cropping and involves growing two or more crops at the same time on the same field. There are four basic variations:**

- **Mixed intercropping: Two or more crops**

**without a distinct row arrangement.**

- **Row intercropping: Same as mixed intercropping but with a distinct row arrangement.**

- **Relay intercropping: Growing two or more crops simultaneously during part of the life cycle of each. The second crop is usually sown after the first has reached its reproductive stage (i.e., around flowering time) but before it is ready to harvest. Example: Planting a climbing bean variety alongside maize that has recently tasseled.**

- **Strip intercropping: Growing two or more crops in separate strips wide enough for independent cultivation, but narrow enough to react agronimically.**

## Monoculture vs. Crop Rotation

**It is difficult to compare the pros and cons of monoculture versus crop rotation since much depends on the crops, soils, management practices, climate and economics involved. Monoculture is frequently blamed for soil "exhaustion" (erosion problems and declining fertility and filth) and a buildup of insects and diseases, yet this is not always the case. Some very productive areas of the U.S. Corn Belt have over 50 percent of their cropland devoted to continuous maize, which yields as well as that grown under crop rotation. In fact, Corn Belt research has shown that continuous maize grown under that region's conditions results in a less serious insect buildup than when maize is grown in a crop rotation with soybeans or pasture and hay. On the other hand, monoculture cotton in the southern U.S. in the 19th and early 20th centuries led to serious soil degradation and insect problems. Monoculture is uncommon under small farmer conditions in developing countries, since intercropping is prevalent and a variety of crops must be produced for subsistence needs. It is mainly confined to perennial cash and export crops such as coffee, sugarcane, citrus, and bananas. Whether or not monoculture is harmful depends on the type of crop and soil management and climate factors. Type of**

**crop:**

- **Row crops which provide relatively little ground cover or return only small amounts of residues (stems, leaves, branches and other debris left in the field after harvest) to the soil are poorly suited to monoculture (i.e. cotton, peanuts, maize or sorghum grown for fodder or silage).**

- **Some crops like beans, potatoes, and many vegetables are especially prone to insects and soilborne diseases which usually build up under monoculture.**

**Soil Management and Climate Factors: A soil's physical condition (filth and permeability), natural fertility, and nutrient-holding ability are directly related to its organic matter (humus) content.**

- **Row crop monoculture will seriously lower soil humus levels unless all crop residues are returned to the soil along with supplemental additions of manure in sizeable amounts (around 30 metric tons/ha or more per year).**

- **The tillage and cultivation operations associated with**

**mechanized (or animal traction) row crop production aereate the soil, which accelerates the microbial breakdown and loss of humus. That is part of the reason why many farmers in the U.S. and Europe have switched to minimum tillage systems such as plowing and planting in one operation. Minimum tillage leads to problems with weeding and herbicidal use.**

- **The problem of humus loss is especially serious in the tropics due to higher temperatures. Decomposition takes place three times as fast as 32°C than at 15.5°C.**

- **Erosion problems associated with row crops are more serious in the tropics due to higher intensity rainfall (even in semi-arid areas).**

**Crop rotation may or may not be beneficial in terms of soil condition, insects, and diseases. In terms of soil condition, the ideal would be to rotate low-residue crops like cotton and vegetables with medium-residue crops like corn, sorghum and rice or, better yet, with pasture, but few small farmers can afford**

**this type of flexibility. Including a nitrogen-fixing legume crop like peanuts or beans in the rotation will not necessarily boost the soil's nitrogen content significantly, since much of the nitrogen produced ends up in the harvested seeds themselves. Some areas have experimented with green manure (legume) crops like cowpeas, which are plowed under around flowering time to add humus and nitrogen to the soil (no harvest is taken), but there are several problems with this approach:**

- **Few farmers are willing to tie up their land growing a non-harvested crop.**
- **The effect of green manure crops on soils is short-lived under tropical conditions.**
- **The green manure crop may use up soil moisture needed by the next crop.**

## Suggested Crop Rotation for the Reference Crops

**The variables are too great to make specific recommendations of wide applicability. Much depends on the area's soils, climate, prevalence and type of intercropping, and common insects and**

**diseases. Some general recommendations can be made:**

- **Crops which share similar diseases (especially soilborne ones like root rots) should not be grown on the same field within three years of each other. For example, peanuts, tobacco, beans, soybeans, and sweet potatoes are all susceptible to Southern Stem Blight (Sclerotium rolfsii), as well as to the same types of nematodes, and should not be grown on the same field in succession.**

- **A crop like peanuts or beans which is especially susceptible to soil-borne diseases should not be grown on the same field more than one year out of three. Again, intercropping may lessen these problems, but not always.**

- **Monoculture is less of a problem if disease-resistant varieties are available and are being continually developed in response to new disease strains.**

## Intercropping (Multiple Cropping)

**Intercropping combinations involving two or more of the**

**reference crops (sometimes along with others) are very common on small farms in the developing world.**

**Intercropping is not ordinarily suited to mechanized farming, but strip intercropping is sometimes used when multiple-row machinery can be operated.**

## The Pros and Cons of Intercropping

### Pros

- **Less risk since yields do not depend on one crop alone.**
- **Better distribution of labor.**
- **Some diseases and insects appear to spread less rapidly under intercropping.**
- **Better erosion control due to better ground cover.**
- **Any legumes involved may add some nitrogen to the soil.**

### Cons

- **Mechanization is difficult.**
- **Management requirements are higher.**

- **Overall costs per unit of production may be higher due to reduced efficiency in planting, weeding and harvesting.**

**The type of muliple cropping is closely related to rainfall and length of rainy season as shown below:**

| Annual Rainfall | Prevalent Type of Multiple Cropping |
|---|---|
| 300-600 mm | Simultaneous mixed intercropping with crops of similar maturities |
| 600-1000 mm | Crop mixes of different maturities |
| Over 1000 mm | Three types of multiple cropping: sequential, simultaneous, and relay |

**Advances in Intercropping Systems**

**Multiple cropping is a diverse and complex subject whose guidelines are often very location-specific. Research interest in multiple cropping has increased markedly over the past decade**

**with most attention being focused on cereal-legume combinations which appear to have the greatest potential, particularly maize or sorghum with beans or cowpeas. The following research results are presented not to imply their direct applicability to a given area but to provide ideas of the many factors involved in intercropping and the state of the art of these complex systems.**

**The National Maize Program in Zaire has been looking into maize rotations and intercropping with legumes to improve soil fertility without commercial fertilizer. Rotations using soybeans and Crotalaria (a green manure crop poisonous to livestock) have been tried. So far, Crotalaria looks superior in nitrogen-fixing ability with the succeeding maize crop, yielding up to 9000 kg/ha. Maize following a soybean green manure crop has yielded up to 6700 kg/ha. The National Maize Program has also worked with an intercrop combination of cowpeas and maize, but has not yet found suitable cowpea varieties.**

**Both rotations and intercropping of maize with legumes appear to offer some promise in Zaire, but there are two main problems:**

- **Legume seeds are harder to store from one year to the next under humid conditions.**

- **Even though legumes used as green manures may contribute a good deal of soil nitrogen, farmers are still likely to need fertilizer, since legumes will not do well on the lowphosphorus soils prevalent throughout much of the tropics.**

**Pearl millet-peanut intercropping trials by the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) in India showed yield advantages of up to 25-30 percent. An arrangement of one row millet to three rows peanuts appeared to provide the optimum balance of competition. Maize-Bean Intercropping Research: The International Center for Tropical Agriculture (CIAT) has run numerous maize-bean intercropping trails at various locations in Colombia. The trials involve simultaneous or near-simultaneous planting of the two crops rather than relay planting. Results were as follows:**

- **For the farmer, the optimum ratio of maize plants to**

**bean plants depends not only on the relative yields but also on the maize-bean price ratiowhich ranges from from 1:2 up to 1:7 in some Latin American countries.**

- **A large number of trials involving simultaneous or nearsimultaneous plantings of maize with beans showed that bush bean yields were decreased by about 30 percent and climbing bean yields about SO percent compared to when grown alone.**

- **Maize yields were usually not adversely affected by the association with beans at a maize population of 40,000 plants/ha. Maize plant densities over 40,000/ha decreased bush bean yields by shading, while densities below 40,000/ ha lowered climbing bean yields because of inadequate support.**

- **At 40,000 maize plants/ha, relative yields of the two crops were best at bush bean densities of 200-250,000 plants/ha and at climbing bean densities of 100-150,000 plants/ha.**

- **Yields of climbing beans were highest when they were planted simultaneously with maize; bush bean yields were highest when the beans were planted one to two weeks before maize, although this caused a significant yield decrease in the maize. Results varied with temperature and the relative early vigor of the bean and maize seedlings.**

**In a 1976 Center for Tropical Agriculture, Research and Training (CATIE) trial in Costa Rica, intercropped populations of 50,000/ha for maize and 200,000/ha for bush beans were found to be the best combination and produced yields of 3400 kg/ha and 1800 kg/ha respectively. A 1976 study in the Minas Gerais area of Brazil by the Universidade Federal de Vicosa focused on relay intercropping of maize and beans. Maize populations of 20-, 40-and 80,000 per hectare were intercropped with climbing beans at 100-, 200-, 300- and 400,000 plants/ha. The maize was planted in the wet season, and the beans were planted between the maize rows when the maize was nearing maturity. The following results were obtained:**

- **Maize yield was not affected by the beans and was highest at 60,000 plants/ha.**

- **Bean yields were highest at the lowest maize population and were not affected by bean plant density.**

- **Even though the beans were planted as the maize was starting to dry out, the maize still exerted a strong competitive effect, mainly due to shading. When grown alone under trellising, the bean variety normally yielded 1200-2000 kg/ha at a density of 250,000/ha, but yielded 800 kg/ha when grown with a maize population of 20,000/ha. Cowpeans-Millet-Sorghum: Experience in Africa has shown that cowpea yields are reduced about 45-55 percent when intercropped with millet and sorghum. However, when grown alone, the improved cowpea varieties become more prone to serious insect attack and often require chemical pest control. Furthermore, intercropped cowpeas are not usually sown until later in the wet season and are viewed more as a bonus crop which does not reduce the millet and sorghum**

**yields.**

**Improving Traditional Multiple Cropping Systems**

**In southeast Guatemala, small farmers usually plant maize, sorghum, and beans by hand on steep to rolling rocky land, and yields average around 530, 630 and 410 kg/ha respectively. Due to a severe labor shortage for planting at the start of the season, the farmers plant the beans in dry soil. They then overplant the maize and sorghum once the rains arrive without regard to where the yettogerminate beans are. With the local varieties used, if the beans emerge first, they will dominate the maize and sorghum; the reverse will happen if the maize and sorghum germinate first. Hoping for a balanced harvest, the farmers are in a race agains time to finish planting the maize and sorghum before the beans germinate. The main disadvantage of this traditional system is the risk that the dry-planted beans may receive only enough rainfall to germinate without sufficient additional precipitation to sustain growth (i.e., a wet season "false start").**

**Researchers have experimented with several alternatives. The**

**most promising one involves strip intercropping of maize, sorghum, beans and cowpeas.**

**At the start of the wet season, beans are planted in strips consisting of three rows spaced 30cm apart. Sufficient space is left between these strips to accommodate sets of double (twin) maize rows with two "varas" (164.0 cm) between the centers of the twin rows. Two or more of these twin row sets of maize can be planted between bean strips depending on the desired cropping mixture. The 30 cm bean row spacing is unusually narrow but gives better weed control due to earlier inter-row shading. Also, the strips are narrow enough to be hand-weeded from the sides to avoid soil compaction or trampling the plants.**

**Once the beans emerge, the maize rows are planted. If the rains stop for a while after bean planting, maize sowing can-be delayed without danger of the beans dominating the young maize seedlings (one advantage of strip intercroping). The beans are a short season variety that matures in 60-65 days.**

**As soon as the beans are harvested, a short season sorghum**

**variety is planted in the space between the sets of twin maize rows. Later, the nearly mature maize plants are doubled over to reduce any shading of the young sorghum plants, which are slow starters. This points the ear tips downward, preventing water entry (which favors fungal grain rots) and reducing bird damage.**

**About two weeks before the maize is doubled, cowpeas are sown along the outer edges of the twin maize rows (i.e., along the edges of the harvested bean strips). The leaves of the maize plants are stripped off as they die off with maturity and used as a mulch (soil covering) to conserve soil moisture. The cowpeas use the maize stalks to climb on and cause no competition due to their late planting.**

## Shifting Cultivation As a Cropping System

**Shifting cultivation (slash and burn agriculture) is a traditional cropping system that was once widely practiced throughout the humid tropics. Due to increasing population pressure on land, the system is now mainly confined to the dense forest areas of the Amazon Basin, Central and West Africa, and Southeast Asia.**

**While there are some variations, shifting cultivation consists of three major steps:**

**1. The land is incompletely cleared by hand cutting and burning trees and other vegetation. The burning has several effects:**

- **All the vegation's nitrogen and sulfur is lost to the atmosphere as gasses. However, the other nutrients (phosphorus, potassium, calcium, etc.) are deposited on the ground as ash.**

- **Even though much organic matter is lost, a lot has already been added to the soil over the years by leaf fall and root decomposition.**

- **Burning only kills some insects, diseases, and weed seeds, not all of them.**

**2. Crops are grown on the land for two or three years, usually under some form of intercropping that may include long-cycle crops such as manioc (cassava) and yams in**

**humid regions. Little, if any, tillage (hoeing, etc.) is required for seedbed preparation, since the soil is usually in good physical condition as a result of the previous fallow. The crops utilize the naturally accumulated nutrients from the fallow period. Yields are fair the first year, but then rapidly decline, causing the land to tee temporarily abandoned after several years of cropping.**

**3. The land is then allowed to revert to a natural vegetation fallow for 5-10 years in order to "rejuvenate" the soil in several ways:**

- **The vegetation, especially if it consists largely of trees and other deep-rooted species, recycles leachable nutrients like nitrogen and sulfur that may be carried into the soil by rainfall during the cropping and fallow periods. Some of the fallow vegetation may be leguminous and actually add nitrogen to the soil.**

- **The fallow increases the amount of soil humus** which is a vital storehouse and source of nutrients, as well as being a great improver of soil physical condition.

- Small, but significant, amounts of nitrogen are produced by lightning, and these are added to the soil by associated rainfall.

The fallow period also helps avoid a buildup of pests and diseases. Shifting cultivation requires no outside inputs and is in complete harmony with the natural environment of the humid tropics. However, the system's success depends heavily on maintaining an adequate length of fallow cycle. As the frequency of clearing and burning increases, trees and brush are eventually killed off . and give way to a very inferior grass (savanna) fallow, which is shallowrooted, inefficient at recycling and accumulating nutrients, and very difficult to clear off for cropping. (Many tropical grass species are actually stimulated into dense regrowth by burning.) Under these conditions, slash and burn agriculture becomes a menance to the environment,

**causing severe deforestation, erosion, and soil exhaustion. Many areas of Central America have been denuded in this manner.**

**Improving Shifting Cultivation:**

**As explained, the system is basically suited only to the humid tropical forest zones under low population density. European attempts to replace shifting cultivation in parts of Africa with "modern" agriculture usually met with disaster (erosion, pests, diseases, and a serious decline in soil condition). Some tropical soils have an iron-rich laterite layer which may become exposed through erosion. Unless such soils are kept under continuous shade, the laterite can harden irreversibly, making them useless.**

**Listed below are some of the most promising possibilities for improving shifting cultivation:**

- **The "Taungya" system of Burmese origin involving agriculture and forestry; it basically** consists of clearing land for a cropping cycle followed by planting fastgrowing trees to provide lumber and rural improvement. Both phases would be operating simultaneously within an area.

- Using fertilizers (chemical or organic) to increase yields during the cropping period.

- Seeding the fallow area with specially selected plants that may be more beneficial than the natural species; the improved fallow might include dense growing vining legumes or leguminous trees and shrubs.

## Land preparation for cropping

On small farms, land preparation methods for the reference crops may or may not involve actual tillage (working the soil with hoes, plows or other equipment) or seedbed shaping (leveling land or making raised beds or ridges).

## Methods Involving No Tillage or Seedbed Shaping

**Under conditions of shifting cultivation, low management or steeply sloping or rocky soils, land is often cleared by simply slashing and/or burning, followed by making the seed holes with a planting stick or hoe. No attempt is made to actually till the soil or to form a specific type of seedbed.**

- **Slash, burn and plant: This method is most suitable for sandy soils which are naturally loose or for other soils that are maintained in good filth (a loose, crumbly condition) by a lengthy vegetative fallow which produces soil humus. It may be the only feasible method for rocky soils or those with pronounced slopes where tillage would accelerate erosion.**

- **Slash, mulch and plant: This method is suited to the same conditions. The vegetation is slashed down or killed with a herbicide and then left on the surface to form a mulch (a protective covering). The seeds may be planted in the ground or may even be scattered over the ground before slashing. The mulch is valuable for erosion and weed control, conserving soil moisture, and keeping soil**

**temperatures more uniform. The International Institute for Tropical Agriculture (IITA) has found this system very beneficial for maize and cowpeas and has developed two types of handoperated planters capable of planting seed through a mulch.**

**There is nothing basically wrong with either of these methods. However, in some cases, tillage and seedbed shaping may have some important advantages:**

- **Soils prone to drainage problems due to topography, soil conditions or high rainfall usually require the use of raised beds or ridges for successful crop production (except for rice).**

- **If liming is needed to correct excessive soil acidity, it must be mixed thoroughly into the top 15-20 cm of soil to be fully effective.**

- **Chemical fertilizers containing phosphorous and potassium and organic fertilizers should be incorporated** several centimeters into the soil for maximum effectiveness. Under non-tillage methods, they can still be correctly applied using a hoe or machete, but it is definitely more work. Chemical fertilizers containing phosphorus are best applied to the reference crops in a band 7.5-10 cm deep that parallels the crop 5-6 cm to one side. A fertilizer furrow can be made easily with a wooden plow or other animaldrawn implement.

- Most animal- or tractor-drawn planters require a tilled seedbed for successful operation. There are exceptions, however, such as the IITA planters.

## Methods Involving Tillage

Tillage refers to the use of animal- or tractor-drawn equipment or hand tools to work the soil in preparation for planting and has five main purposes:

- To break up and loosen the soil to favor seed germination, seedling emergence, and root growth

- **To chop up and/or bury the previous crop's residues so they will not interfere with the new crop**

- **To control weeds (an ideal seedbed is completely weedfree at planting time)**

- **To incorporate (mix into the soil) liming materials and fertilizers (chemical or organic)**

- **To shape the kind of seedbed most suited to the particular soil, climate, and crop (i.e., raised beds, ridges, flat seedbeds).**

**Primary tillage refers to the initial breaking up of the soil by plowing or using a heavy-duty digging hoe. Depth of plowing usually ranges from about 15-30 cm, depending on the type of plow used, its traction source, and the soil. For example, an ox-drawn wooden plow will not have the penetration ability of a tractor-drawn moldboard plow, especially in heavy soils. Secondary tillage refers to any additional tillage operations between plowing and planting to break up clods, cut up trash, kill**

**weeds, and smooth out the seedbed. It is most commonly performed with some type of harrow (an implement used to pulverize and smooth the soil).**

**Secondary tillage is shallower than planting and requires less power. Ridging and bedding (forming ridges or beds for raised planting) also can be included in this category.**

**Reference Crop Tillage Systems**

**The reference crops share the same basic tillage methods, but these vary with the particular soil, the available tillage equipment, and the need for incorporating lime or fertilizer. There are three basic tillage systems, each with advantages and disadvantages:**

- **Plow (or hoe)/Plant: If plowed at the right moisture level, some soils (especially loams and sands) may be suitable for sowing with a planter without any secondary tillage to break up the clods. Most soils can be hand-planted after plowing, since the farmer has better control**

**over seed depth than when a mechanical planter is used. He can also push any big clods aside or break them up while walking down the row. This type of rough seedbed is actually very advantageous in terms of weed control since the cloddy surface discourages their growth. It also favors moisture penetration and reduces runoff. On the other hand, if bedding or ridging is needed, a better job can be done if any large clods are first broken up by harrowing (cultivating).**

- **Plow/Harrow/Plant: This is the most common system where animal- or tractor-drawn planters are used, unless the soil breaks up well enough under plowing alone. If soil conditions are conducive to weed growth, the ground should be harrowed as close to planting as possible to give the crop a head start on the weeds.**

- **Minimum Tillage: Farmers with access to tractor- or animaldrawn tillage equipment may overdo tillage, especially through repeated harrowings to control sprouting weeds or break up clods. Killing one crop of**

**weeds by stirring the soil only stimulates another by moving other weed seeds closer to the soil surface. Excessive tillage stimulates the microbial breakdown of humus and may further destroy good soil physical condition by over-pulverizing the soil, The machinery, animal, and foot traffic also compact the soil, impairing root growth and drainage. Tillage is seldom excessive when hand tools are used to prepare ground for the reference crops, because of the amount of labor it would involve. Slash-and-burn and slash-and-mulch methods fall under zero tillage, as do methods using specially adapted mechanical planters to sow seed into unplowed ground (common in the U.S.). The plow/plant system described above or plowing and planting in one tractor pass are examples of minimum tillage. The savings on equipment wear and fuel are advantages where tractors are used.**

## Tillage and Seedbed Fineness

**The degree to which clods need to be broken up depends mainly on seed type and seed size and whether hand planting or**

**mechanical planting will be used.**

**1. Seed type: Maize, millet and sorghum are monocots with seedlings that break through the soil with a spike-like tip. This reduces the need for a clod-free seedbed. Peanuts and other pulses are dicots, and emerge in a blunt form, dragging the two seed leaves with them; they tend to have more trouble with clods.**

**2. Seed size: Large seeds have more strength than small seeds, enabling young shoots to push more effectively through rough seedbeds. Maize seeds are large monocots, which gives them especially good clod handling ability. Peanuts and the other pulses are large-seeded, but this advantage is partly offset, since they are dicots. The small seeds of sorghum and especially millet are less powerful, but this is offset by the fact that they are monocots. Small seeds require shallower planting than larger ones, and cloddy soils do not allow this type of precision if mechanical planters are used.**

3. Farmers can usually get by with cloddier seedbeds when hand planting. They have more control over planting depth and can push any large clods aside. In addition, it is very common under hand planting to sow several seeds per hole, which gives them a better chance of breating through.

Clayey soils, especially those low in humus, are usually in a cloddier condition after plowing than loamy or sandy ones. Most plowing takes place at the end of the dry season, when soils are very dry, which accentuates the problem. Rainfall following plowing may significantly reduce clod problems on some soils by breaking up the clods.

## Tillage Depth

A plowing depth in the 15-20 cm range is usually adequate, and there is seldom any advantage in going deeper. In fact, shallower plowing is often recommended for low rainfall areas like the Sahel to conserve moisture.

**In some areas, tractor-drawn sub-soilers (long narrow shanks that penetrate down to 60 cm) are used in an attempt to break up deep hardpans (compacted layers). Results are fair to poor, depending on the type of hardpan; those consisting of a dense clay layer often re-cement themselves within a short time.**

**About 65-80 percent of the reference crops' roots are found in the topsoil, since this layer is more fertile (partly due to its higher organic matter content) and less compacted than the subsoil. However, any roots that enter the subsoil can utilize its valuable moisture reserves, making a critical difference during a drought. Proper fertilization of the topsoil will encourage much deeper root development. On the other hand, poor drainage and excessive acidity in the subsoil will hinder or prevent root penetration.**

## Handling Crop Residues

**There are three basic ways of handling the previous crop's residues (stalks, leaves, branches) when preparing land: burning, burying and mulching:**

**1. Burning--This destroys the organic matter contained in the residues, but may be the only feasible solution where suitable equipment is lacking or where time is short.**

**2. Burying--chopping residues up with a disk harrow or slasher and then plowing them under is a common practice in mechanized farming.**

**3. Mulching--Chopping up residues and leaving them on top of the ground has some definite benefits such as greatly reducing soil erosion caused by rainfall and wind as well as water losses due to evaporation. However, there are two disadvantages to mulching which should be considered:**

- **Residues are left on the surface and can interfere with the operation of equipment such as planters, plows, and cultivators which may plug up.**

- **Mulching is not recommended for peanuts, especially in wet regions, since they are very** susceptible to Southern stem rot (Sclerotium rolfsii), which can incubate on unburied residues from any type of plant (see page 243).

## Animal versus Tractor Power: Some Considerations for the Small Farmer

In the developing countries, tractor power and its associated equipment are mainly confined to large farms and to areas where labor costs are high. The large investment, fuel and repair costs, and maintenance requirements all weigh heavily against the purchase of such machinery by small farmers. Spare parts and the necessary repair facilities are commonly lacking, meaning that a breakdown can be disastrous. A study by ICRISAT on the economics of full-size tractors in India showed new evidence that they significantly increase yields, cropping intensity, timeliness or gross returns per hectare. Money can usually be much better spent on animal traction equipment, improved seeds, fertilizers, and other highreturn inputs.

However, there are two situations where tractor power can be

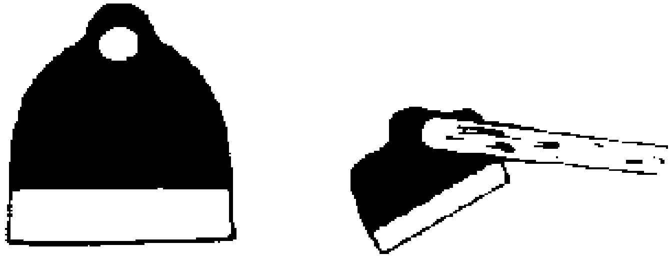
**justified:**

- **Animal-drawn equipment may not be sufficient to meet the production needs of the intermediate farmer who has about 5-20 ha of land. In this case, small horsepower equipment may be very suitable. The International Institute for Tropical Agriculture (IITA) farming systems program has developed a 5 hp gasolinepowered multipurpose equipment unit that can plant field crops with a two-row "punch" planter, haul 500 kg in a trailer, and convert to a walk-behind tractor for rotary tillage, ridging, brush slashing, and plowing rice paddies. Other types of low-horsepower units are available from other manufacturers.**

- **The small farmer can sometimes benefit by hiring tractor work on an as-needed basis during peak periods when his normal labor supply is insufficient to meet demands.**

## Basic Tillage Equipment for Plowing and Harrowing

**Hand Implements: Heavy duty digging hoes can be very effective for small areas. In Kenya, for example, nearly all small holdings are prepared this way, although an average family cannot handle much more than 0.5 ha with this method. In a wet-dry climate, most land preparation takes place when the soil is hard and dry, which poses added obstaces for hand tools. Some extension services recommend that land be prepared at the end of the previous wet season before the soil dries out. However, this is not always possible due to standing crops.**



**A digging hoe and a heavy duty hoe blade.**

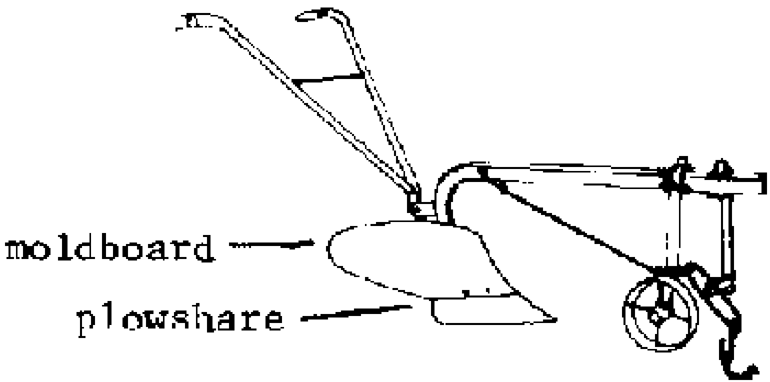
**One common type of wooden plow. Most of them have metal tips to reduce wear.**

**Wooden Plow: Designs of wooden plows go back many centuries. They often are animal drawn, and some have a metal tip. They do not invert the soil or bury crop residues but basically make grooves through the soil. Their effectiveness depends a lot on soil type and moisture content. The grooves they make also can serve as seed and fertilizer furrows.**

**Moldboard plow: This is the ideal plow for turning under grass, green manure crops, and heavy crop residues such as chopped-up maize stalks. It also buries weed seeds deeper and damages perennial weeds more than other equipment. Moldboard plows**

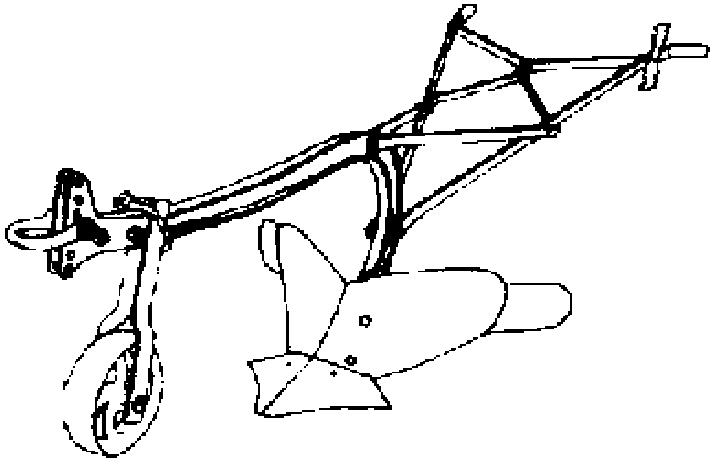
**are available in animal-drawn models (usually just one plow bottom) and tractor models (usually two to six bottoms). Depending on plow size (width of the moldboard as viewed from the front or back) and soil condition, they will penetrate to 15-22 cm.**

**Unless equipped with a spring trip device, moldboards do not handle rocky soils well. They are not as well suited to drier areas as disk plows. They also encounter problems in sticky clay soils and may form a plow pan (a thin compacted layer that can hinder root growth) if used at the same depth year after year.**



**A moldboard plow. The moldboard section is curved so that it turns over the soil slice that is cut by the plowshare.**

**Disk Plow: Better suited than the moldboard to hard, clayey, rocky or sticky ground, but does not bury residues as effectively. This is an advantage in drier areas where surface residues reduce wind and water erosion and cut down moisture evaporation. Disk plows are not recommended for peanut ground where Southern stem rot is a problem, because surface plant residues harbor the spores. They also will not do an effective job turning under grass sod. Disk plows are mainly available in tractor-drawn models. Unlike moldboards plows, they are less likely to form a plow pan if used at the same depth year after year.**



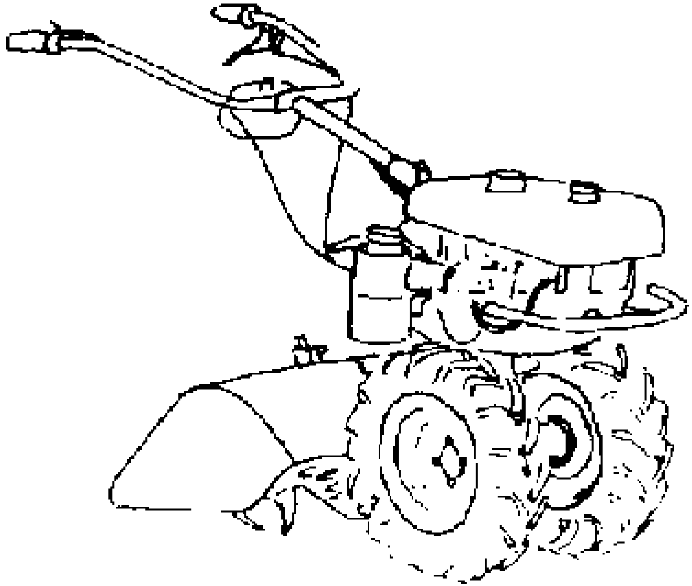
**A ridging plow or middlebreaker for making raised beds or ridges**

**Ridging Plows (Lister Plows or "middlebreakers"). These basically consist of a double-sided moldboard that throws soil both ways. This will produce a series of alternating furrows (trenches) and ridges when operated over a field. Depending on the climate and soil, the crop is either planted in the furrows (in low rainfall areas with no drainage problems) or on top of the ridges (in high rainfall areas or those with drainage problems). Such furrow planting is advantageous in drier areas for cereal crops, since it conserves moisture. Soil is thrown into the row as**

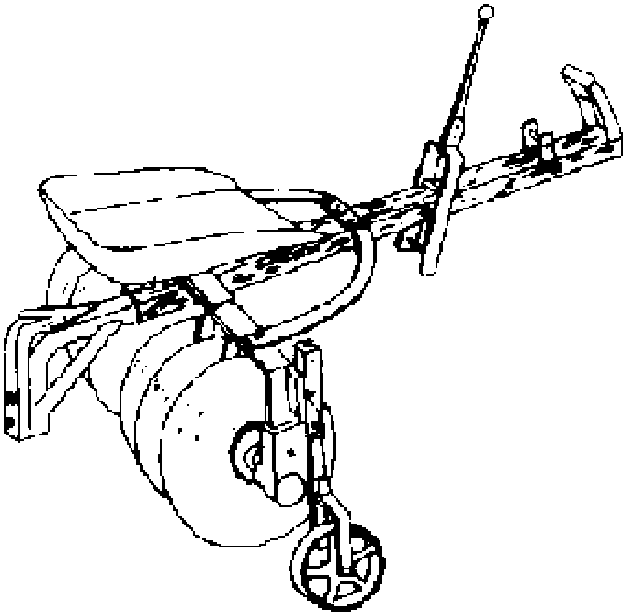
**the season progresses for weed control, and this also sets the roots deep into the soil, where moisture is more adequate. Such furrow planting is not recommended for peanuts and often not for beans due to increased root rot and stem rot problems.**

**Rototillers (rotovators):**

**These are available in tractor-powered models. They throroughly pulverize the soil and partially bury crop residues. Heavy duty models can be used for a once-over complete tillage job. The disadvantages are that power requirements are very high and the soil can be easily overworked with this implement. In fact, rototillers do a far more thorough job of seedbed preparation than is needed for the reference crops and are best used for vegetable ground.**



**A rototiller or rotavator. Note the revolving blades under the hood behind the wheels.**



**Animal-drawn disk harrow**

**Disk Harrows: Disk harrows are commonly used after plowing to break up clods, control weeds, and smooth the soil before planting. They are also used to chop up coarse crop residues before plowing (especially if a moldboard or disk plow will be used), but heavier models with scalloped disks (disks with large**

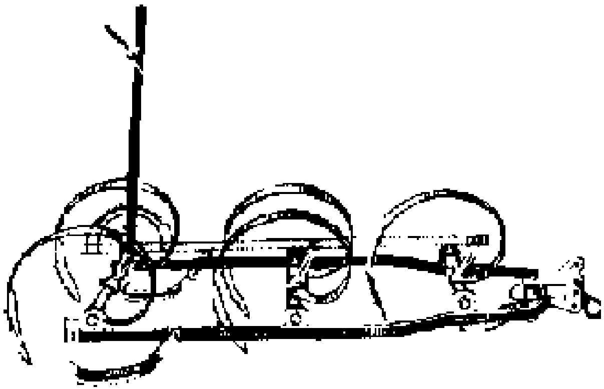
**serrations) are most effective for this purpose. Both animal and tractor-drawn models are available but they are expensive and prone to frequent bearing failure unless regularly greased. Large, heavy duty versions pulled by tractors are often called Rome plows and can sometimes substitute for plowing. The gangs of disks are offset to the direction of travel so that they cut, throw, and loosen the top 7.5-15 cm of soil but pack down the soil immediately below that. Repeatedly harrowing a field prior to planting can actually leave it harder than before plowing if done when the soil is moist.**

**Spike-Tooth Harrows: These consist of a metal or wood frame studded with pegs or spikes; extra weight in the form of stones or logs may be needed under some conditions for maximum effectiveness. They are used to smooth the seedbed and break up clods (at the right moisture content), and are especially suited for killing small weed seedlings that may emerge before planting.**

**Spike-tooth harrows are made in many widths and are classified by weight and the length of the tines. In some cases, this type of harrow can be run over the actual crop rows from several days**

**after planting up until the seedlings are a few centimeters tall to control early geminating weeds or to break up any soil crusting. Spike-tooth harrows will clog up if trash is left on the soil surface.**

**Two models of a spike-tooth harrow**

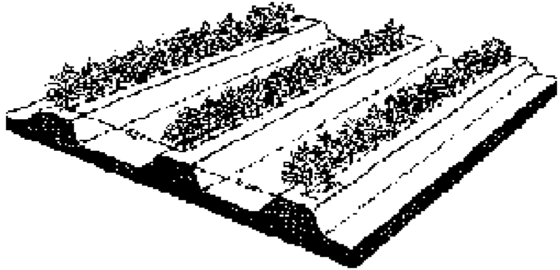


**A spring tine harrow**

**Spring-Tooth Harrows: These have tines made from spring steel that dig, lift, and loosen the top 7.5-10.0 cm of soil, break up clods, and smooth out the seedbed. Both animal and tractor-drawn models are available. They are not suited to hard or trashy ground but handle stones well.**

**Field Cultivators: These are similar in appearance to chisel plows, but usually are not as built as heavy. They can be used for initial tillage on ground with little surface residue, but are mainly used as a secondary tillage implement for weed control. Most models are designed for tractor use.**

**(Additional information on the use of animal-drawn equipment can be found in Animal Traction, U.S. Peace Corps Appropriate Technologies for Development Manual Series #12, by Peter Watson, 1981.)**



**Beans grown on raised beds**

## Seedbed Shape

**The best seedbed shape depends more on the climate and soil involved than on the particular reference crop.**

**Flat Seedbeds: This shape is used where soil moisture is adequate for crop growth and where there are no drainage problems. Under such conditions, the reference crops are often planted on a flat seedbed and then "hilled up" with soil (soil is moved into the crop row and mounded around the plants) as the season progresses to control in-row weeds, provide support, and improve drainage. In warm, humid areas where stem rot is a problem, this practice is not recommended for peanuts.**

**Raised Seedbeds (Ridge or Bed Planting): Under heavy rainfall and/ or poor drainage, the reference crops are usually planted on ridges or raised beds to keep them from getting "wet feet". This also helps minimize soil-borne disease problems like root rots and helps control water erosion if the ridges are run on the contour. Water infiltration is encouraged and runoff minimized. In addition, ridge planting makes for easier entry of digging equipment when peanuts are harvested. Finally, more topsoil is provided for crop growth under this system. The main disadvantage of ridge planting is the accelerated loss of soil moisture from the mounds--normally not a serious problem in wet areas except during dry spells. In drier areas mulching would be beneficial. In regions where the wet season starts out slow, the crops may be flatplanted and then later "hilled up" as the rains increase. Furrow irrigation always requires ridge planting.**

**Furrow Planting: Under conditions of low rainfall or poor soil water-holding capacity (i.e., sandy soils), crops are often planted in the furrow bottom between ridges where soil moisture is greater. Soil can then be thrown into the furrows to control in-row weeds and improve drainage (if rainfall picks up) as crop**

growth progresses. This type of sunken planting is not recommended for peanuts in moist areas, since it encourages stem and root rots, particularly if soil is thrown into the row.

Note: Local farmers usually have good seedbed experience, so beware of tampering with time-tested methods without first considering all the angles and running some trials.

## Equipment for Seedbed Shaping

Flat seedbeds usually require no special efforts beyond plowing and possibly harrowing. If additional land leveling is required, the small farmer without access to special tractor-drawn leveling equipment can do a satisfactory job dragging a heavy board hitched to two draft animals over the field.

Ridges or beds can be made with digging hoes, special ridging plows (see tillage equipment section) or tractor-drawn disk-bedders (rolling disks arranged at opposing angles to throw soil up to form beds). The crop can be planted either on top of the ridges or in the furrows, depending on the soil and climate.

**Summary of land preparation recommendations for the reference crops**

**Land preparation is a very location-specific practice varying with climate, soil type, crop, management level, and available equipment. The following is a summary of the principal factors involved in choosing the most feasible and appropriate land preparation method and seedbed shape for the reference crops:**

1. **Seedbed Fineness (thoroughness of preparation)**

   - **Maize's large seeds and spikelike emergence gives it the best clod-handling ability of the reference crops.**

   - **Rough (cloddy) seedbeds discourage weed growth and reduce erosion caused by rain or wind; they also increase water retention by cutting down water runoff.**

   - **The reference crops can tolerate a rougher seedbed when planted by hand than when typical**

**mechnical planters are used.**

- **To cut down on soil compaction and other effects of overworking the soil as well as to reduce labor, machinery and fuel costs, it is best to use the minimum amount of tillage consistent with adequate seedbed preparation.**

**2. Tillage Depth**

- **There is seldom any advantage to plowing deeper than 15-20 cm.**

- **Shallower plowing may be advisable in drier areas to reduce wind erosion and moisture losses.**

**3. Crop Residue Management**

- **Leaving crop residues on the soil surface is especially advantageous in drier areas since it reduces moisture losses and wind erosion. It also reduces erosion due to rainfall and increases water**

**retention.**

- **When growing peanuts (and sometimes beans), complete residue burial is usually recommended where Southern stem rot (Sclerotium) is a problem, since the disease can incubate on surface plant residues.**

- **With the other reference crops, surface residues may sometimes aggravate certain insect and disease problems.**

**4. Suitability of Equipment**

- **The moldboard plow is the most effective implement for burying crop residues and grass sod.**

- **A disk plow is better suited than the moldboard to hard, clayey, rocky or sticky ground but does not bury residues or grass sod effectively.**

- **Chisel plows are best suited to lower rainfall**

**areas and leave trash on top of the soil. They are fairly ineffective on wet soils.**

- **Disk harrows handle clods better than spike- (peg) tooth and spring-tooth harrows but are more costly and prone to repair problems.**

**5. Seedbed Shape**

- **Ridge planting is recommended for all the reference crops under high rainfall or poor drainage.**

- **Flat planting is best suited to soils with good drainage. However, soil can be mounded into the crop row as growth progresses to control weeds and improve drainage if rainfall increases.**

- **Furrow planting is best suited to low rainfall areas since it conserves moisture.**

- **Peanuts and beans are especially susceptible to** root rots favored by excess moisture. They should be either flat-planted or ridgeplanted.

## Seed selection

### Factors Affecting Variety Selection

The selection of a locallyadapted variety with good yield potential and acceptable grain characteristics is fundamental to successful crop production. There are several important varietyrelated characteristics that should be considered when selecting seeds:

1. Yield potential: This is related to inherent natural vigor and other characteristics listed below.

2. Time to maturity: Varieties fall into three general maturity classes: early-, medium-and late-maturing (when grown under similar temperatures). Early varieties produce a crop more quickly, but yields may be about 10-15 percent lower compared with slower-maturing types if both receive adequate moisture. However, early varieties are especially well suited to short rainy seasons or

**sequential cropping. Since temperature has a strong influence on a variety's actual length of growing period, some countries like the U.S. are now labeling maize varieties in terms of the growing degree days (total heat units) required for maturity rather than calendar days.**

**3. Elevation adaption: This has to do with a variety's time to maturity and growth ability at different elevations and temperatures. In regions with pronounced variations in elevation such as Central America, the Andean countries, and Ethiopia, maize and sorghum varieties are classified according to their elevation adaption (i.e., 01000, 10001500, etc.); a similar system may also be used for beans and other pulses.**

**4. Heat or cold tolerance: Varieties vary in their tolerance to excessive heat or cold.**

**5. Drought tolerance: Even varieties within a crop can vary considerably in this respect. In a 1978 International Maize and Wheat Improvement Center (CIMMYT) maize trial, a**

**variety selected for drought tolerance outyielded the best fullirrigation variety by 64 percent under conditions of severe moisture shortage.**

**6. Resistance (partial tolerance) to insects, diseases, and nematodes, as well as to bird damage and soil problems such as excessive acidity and low phosphorus levels. Reference crop varieties can differ considerably in their tolerance to these problems, which are some of the major concerns of plant breeding work. Resistance to lodging also is an important consideration in selecting a maize variety.**

**7 Growth habit and other plant characteristics: For example, bean varieties can be bush, semi-vining or vining in their growth habit; millet varies in tillering ability and sorghum in its ratooning potential (see page 55). Plant height and the ratio of leaf and stalk also varies with variety.**

**8. Daylength sensitivity (photosensitivity) varies markedly**

among sorghum and millet varieties (see page 45).

9. Seed color, shape, size, storability, etc.

**Traditional Versus Improved Varieties**

In selecting a variety, it is important to understand the differences between traditional varieties, hybrids, synthetics, and other improved varieties.

1. Traditional (local) varieties: They tend to be relatively lowyielding but are usually hardy and have fair to good resistance to local insect and disease problems. However, most are adpated to low levels of soil fertility and management and often do not respond as well as improved types to fertilizer and other improved practices. Native varieties of maize, sorghum and millet tend to have an overly high ratio of stalk and leaves to grain, but this may be an advantage where livestock are important.

Despite certain disadvantages, local varieties may be the best choice in some situations During the first years of the

**Puebla maize project in Mexico (see page 80), some of the local varieties consistently outyielded anything the plant breeders could come up with.**

**2. A hybrid is a type of improved variety produced by crossing two or more inbred lines of a crop. This is relatively easy to do with maize and sorghum, and a number of hybrids are available to these two crops. Hybrid development in peanuts, beans and the other pulses has proven more difficult, and they are not yet generally available. Millet research is still at too early a stage for hybrids to assume much importance.**

**When grown under similar conditions, an adapted hybrid may out-yield the best adapted, normally-produced varieties by 15-35 percent, but not always. Despite these possible yield benefits hybrids have several disadvantages:**

- **Unlike naturally produced varieties, the seed harvested from a hybrid should not be replanted by the farmer. If reseeded, a hybrid begins to degenerate and revert back to**

**the original (and usually less desirable) lines from which it was developed. Yields may drop as much as 15-25 percent each successive crop. Many small farmers lack the inclination or the money to buy new seed for each planting unless special arrangements and educational efforts are made.**

- **Hybrid seed may be several times more expensive than that of other types.**

- **Hybrids require good management or they may not yield much more than other types.**

- **Hybrids show a narrower range of adaptation to different growing conditions than other varieties; this makes finding a suitable hybrid more difficult. It is estimated that 131 different hybrids had to be developed to suit varying maize growing conditions in the U.S.**

**3. Synthetics are improved varieties that have been developed from crosspollinating lines (naturally pollinated**

**with no purposeful inbreeding as in hybrids). These lines are first tested for their combining ability and then crossed in all combinations. Synthetic varieties often yield as well as hybrids under small farmer conditions and have several advantages over them:**

- **They have greater genetic variability than hybrids, which makes them more adaptable to different growing conditions.**

- **The seed costs less than that of hybrids.**

- **Unlike hybrids, seed harvested from a synthetic can be replanted without loss of vigor as long as farmers are willing to select it from the plants with the best characteristics.**

**4. Varieties improved through mass selection: This is the most elemental form of varietal improvement and consists of natural crossing between lines with no attempt made to test for combining ability (as with synthetics) and**

continually selecting seed from plants showing the best combination of desirable characteristics. While yields may not be as good as those from hybrids or synthetics, the seed is cheaper and also can be replanted.

**Guidelines for Selecting Quality Seed**

**Seed quality can be influenced**

**by the following factors:**

1. Varietal purity: Farmers who use their own harvested seed for replanting can be reasonably assured of varietal purity, especially with crops that are naturally selfpollinated (millet, sorghum, peanutes, cowpeas, beans, and most other pulses). Since maize is cross-pollinated, there is opportunity for "contamination" from other nearby maize varieties. This can be minimized by selecting seed for replanting from the inner part of the field.

Commercially available seed may or may not have good varietal purity, depending on its source and the country's

**commercial seed standards. In some areas, certified seed is available with guaranteed genetic purity and tested germination.**

**2. Germination and vigor depend largely on the seed's age and the conditions under which it has been stored. High temperature and humidity as well as insect damage (weevils, etc.) can drastically reduce both germination and vigor. Certified seed is usually labeled with a tested germination percentage, but post-tested storage conditions can make this a worthless guarantee. You should encourage farmers to run their own germination test (see page 121) before planting any seed, regardless of source.**

**3. Visual traits: Mold, insect damage, cracking, and shrunken or shriveled seed mean trouble.**

**IMPORTANT NOTE: Beans, soybeans and shelled peanuts are very susceptible to damage from rough handling of dry seeds in harvesting, processing, and shipping. Dropping a**

**sack of beans on a cement floor is enough to harm them. Both the seedcoats and sects crack very easily; careless handling can also cause invisible damage. In both cases, these injuries can lead to stunted, malformed seedlings lacking in vigor.**

**4. Impurities such as weed seeds; These are more of a problem in crops with small seeds like millet and sorghum, where separation is more difficult.**

**5. Seed-borne diseases: Some diseases like anthracnose may show visible symptoms on contaminated seed, while many others do not. Certified seed, if grown under the proper procedures of inspection and roguing (elimination of diseased plants), is free from certain seed-borne diseases and is especially recommended for beans when available. Some common fungal diseases are carried mainly on the seed coat surface and can be controlled by dusting the seed with a fungicide; others (especially viruses) are internal and have no control (see page 250).**

## How to Select Home Grown Seed

**Most farmers not using hybrid will set aside some of their harvested seed for replanting future crops. This is fine as long as the variety is suitable, storage methods are adequate, and seed-borne diseases are not a problem. If the guidelines below are followed, the farmers actually may be able to improve the varieties they are using or at least prevent a decline in their performance:**

> **1. Seed selection should start while the crop is still growing in the field: Most farmers wait until after harvest to select seed for replanting and go largely by seed or ear size. Selecting maize seed from the largest ears may have little, if any, value. This is because the ear's size may be due less to the plant's inherent genetic ability than to environmental or management factors like fertility, plant density, and available moisture.**
>
> **2. When selecting plants as potential seed sources, keep in mind the important plant characteristics that favor good**

**yields:**

- **General: Resistance to disease, insects, drought and nematodes; general plant vigor, ratio of stalk and leaves to grain, and time to maturity.**

- **Maize: Resistance to lodging, extent and tightness of husk covering (for insect, bird, and water resistance), and number of well-formed ears per plant.**

**When selecting maize plants, make selections from well within the field to avoid possible cross-pollination, so this is not a problem with them.**

**3. Mark the selected plants with cloth or stakes.**

**4. Additional guidelines for maize: When choosing among good ears after harvest, physical differences like the number of kernel rows, kernel size, and filling of the tips and butts of the cob are relatively useless as indicators of yield potential. However, the very small, misshapen seeds**

at the extreme ends of the cob should be discarded. Check also for uniformity of kernel color and for insect damage.

## How to Conduct a Germination Test

Farmers should be encouraged to run a germination test on seed before planting, regardless of the source. The same holds true for extension workers receiving shipments of improved seed. Germination figures that appear on seed labels can be inaccurate even if the tests were conducted fairly recently. Warm, humid conditions in the tropics can rapidly lower the germination rate. To run the test:

- Count out 100 seeds and place them on top of several thicknesses of moist newspaper. Spread them out enough so you can distinguish which ones have germinated.

- Carefully roll up the moist newspaper so that the seeds remain separated from each other and stay pressed against the newspaper. Place in a plastic bag or periodically re-moisten the newspaper to keep it from

**drying out.**

- **Sprouting time will vary with temperature, but you should be able to get a good idea of germination within three to five days unless it is unusually,cold. Good seed should have a germination rate of at least 80-85 percent under these conditions. Up to a point, you can compensate for low germination by planting more seed, but below a rate of 50 percent or so seedling vigor may suffer also.**

**It is a good idea where possible to supplement this type of test with an actual field test, since soil conditions are not usually as ideal. Plant 50100 seeds, keep the soil moist enough, and then count the emerged plants. If germination is very much lower than with the newspaper method, do some troubleshooting to see if insects or seeds may have caused problems.**

## Planting

### The Goals of Successful Planting

**When planting, farmers must accomplish four objectives in order**

**to promote good crop yields:**

**1. Attain an adequate stand (population) of plants. This requires seed with good germination ability, adequate land preparation, sufficient soil moisture, correct planter calibration (adjustment) if mechanical planters are used, proper planting depth, and control of soil insects and diseases that attack seeds and young seedlings. In some areas, birds and rodents also cause problems.**

**2. Attain the desired plant spacing both in the row and between the rows.**

**3. Observe timeliness in land preparation and planting. The right time to plant depends on the crop's characteristics (i.e., peanuts should be planted so that harvesting will be likely to occur during reasonably dry weather), the onset of the rains and overall rainfall pattern, the influence, if any, of planting date on insect and disease problems such as sorghum head mold.**

4. Use the right type of seedbed for the particular crop, soil, and climate (see page _).

## Planting Methods And Equipment

1. Hand planting with a planting stick, hoe or machete: This is the most common method used by small farmers in the developing world.

### Advantages

- Equipment costs are negligible.

- Less thorough seedbed preparation is needed than for most mechanical planters. The farmer who hand plants can push large clods out of the way while walking down the row or can plant directly into untilled soil.

### Disadvantages

- Time and labor requirements are high: it takes three or four person-days to plant a hectare by hand.

- When hand planting, farmers usually put several seeds in each hole and space the holes rather far apart, partly to save labor. This practice can often reduce yields by resulting in too low an overall seeding rate and too much competition among the plants that emerge from the same hole.

## 2. Improvements in Hand Planting

- Hand-operated, mechanical "punch" or "jab" planters are available that make the planting holes and drop in the seed in one movement (the seed is automatically metered out from a reservoir). They are operated like an ordinary planting stick (jabbed or punched into the ground) but are much quicker and are also very useful for filling in any "skips" (vacancies) in larger fields. A hectare of maize can

**be planted in 15-20 personhours. The farming systems program of IITA in Nigeria has designed a very successful punch planter suitable for planting maize, sorghum, cowpeas, beans, and soybeans into untilled ground. It is also capable of planting through a dried mulch. The IITA punch planter can be built in a workshop with access to metal shears (no welding is needed). (Write IITA for plans.) Other types of punch planters are available commercially in some countries.**

- **Hand-pushed planters: Most models require a fairly loose clod-free seedbed for satisfactory operation. However, IITA's farming systems program has designed a very effective rolling punch planter (called a rotary injection planter, see illustration) that can be built in any workshop with welding and metal-shearing capabilities and is being manufactured by Geest Overseas Mechanization Ltd., West Marsh Road, Spalding, Lincolnshire PE11-2BD, England (price is about**

**$225 U.S.). The rotary injection planter uses the same principles as the hand punch planter, but has six punchinjection devices on a rolling wheel plus a following press wheel to firm down the seed row. The standard design produces a seed spacing of 25 cm, but alternate rollers can be made for different spacings. The rotary injection planter is also available as a four-row, hand-pulled model for planting direct-seeded rice.**

- **Hand planting into furrows made with an animal- or tractordrawn implement: A wooden plow, cultivator shank or other implement can be used to make seed furrows in plowed ground. If certain precautions are followed, the fertilizer can be placed in the same furrow (see page 157).**

- **Reasonably parallel crop rows are required if weeding is to be done with an animal- or tractor-drawn cultivator. Farmers can easily construct a parallel row "tracer" consisting of a wood or**

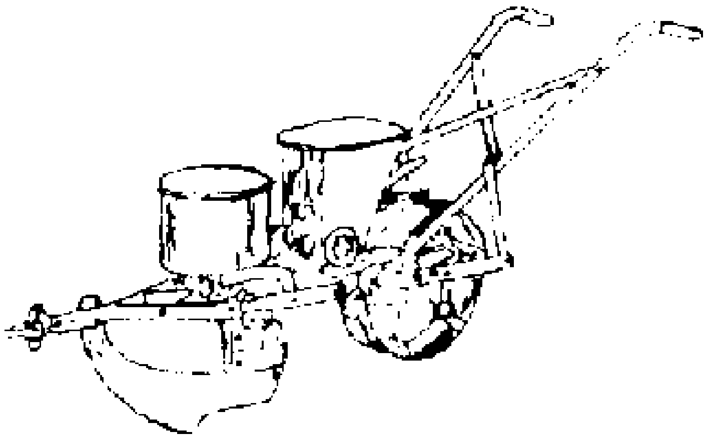
**bamboo frame with hardwood or steel teeth for marking out rows. (A design for this handy implement can be found in the Peace Corps' Animal Traction manual.)**

- **Improved seed-spacing accuracy can be achieved by running a rope or chain down the row with knots or paint marks to indicate the proper spacing. Otherwise, farmers commonly make large errors in spacing when using planting sticks or dribbling out seeds into a plowed furrow.**

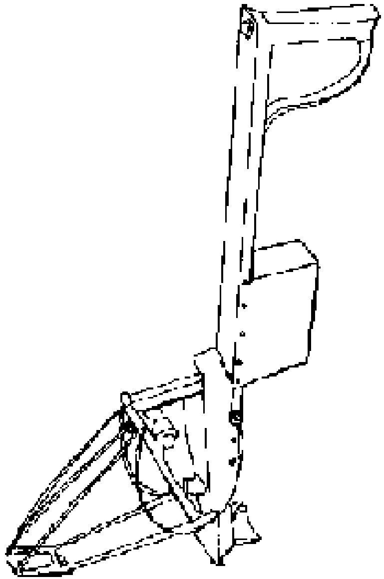
**3. Animal- and tractor-drawn mechanical planters are available in many different models. A farmer using a onerow animal-drawn planter can sow about 1-1.5 ha in a day and about 5-8 ha using a two-row tractor-drawn planter.**

**Here are some important considerations concerning these types of planters:**

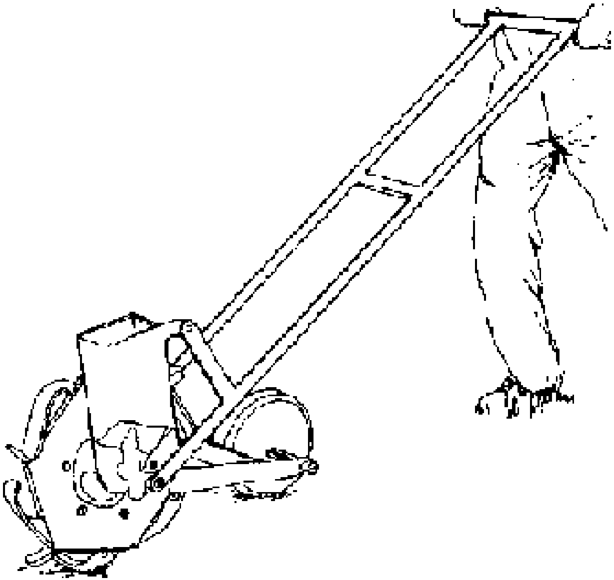
- **Most mechanical planters require a more thoroughly prepared seedbed than is needed for hand planting. Some models have special soil openers that permit satisfactory operation in hard or cloddy soil.**



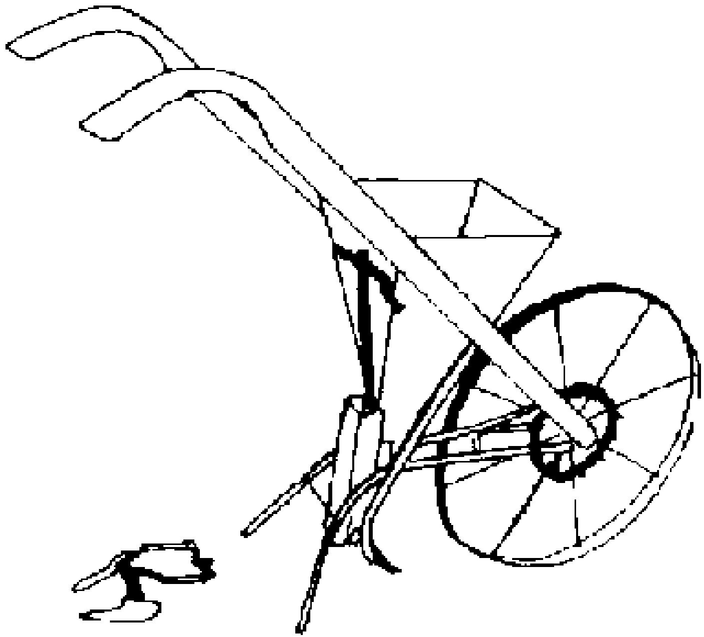
**An animal-drawn planter with a separate hopper for banding fertilizer**



**The IITA designed hand-operated "jab" or "punch" planter, which can be made in a workshop. The attached metal bracket firms the soil over the seed and spaces the next seed insertion.**



**The rolling "punch" planter developed by IITA and now manufactured commercially. It also can be built in a workshop.**



**A hand-pushed fertilizer band applicator. This model places the fertilizer below the soil surface, which is essential for phosphorusbearing fertilizers. The attachment at the left is used to close the furrow but usually is not needed.**

- **The farmer must be able to calibrate (adjust) the**

**planter so that it drops the seeds at the correct intervals along the row (see page 135).**

- **Some models have attachments for applying fertilizer in a band beneath the soil and slightly to the side of the seed row. This is an especially effective method for fertilizers containing phosphorous.**

**Farmers using planters without fertilizer applicators will often broadcast the fertilizer and plow it under before planting or leave it on top of the ground; this should not be done with fertilizers containing phosphorus! Farmers buying mechanical planters should be encouraged to purchase a fertilizer attachment if available and effective. (NOTE: The applicator should not dribble the fertilizer on top of the ground or place it in direct contact with the seed.)**

## Plant Population And Spacing

**Both plant population and spacing affect the yields of the reference crops, and extension workers should understand the relationships.**

## Plant Population and Its Effects on Crop Yields

- **Up to a point, crop yields will increase along with increases in plant population until the competition for sunlight, water, and nutrients becomes too great.**

- **Excessively high populations will reduce yields, encourage diseases, and seriously increase lodging in maize, sorghum and millet by promoting spindly, weak stalks.**

- **Excessively low plant populations will cut yields due to unused space and the limitations on maximum yield per plant.**

- **Under most conditions, changes in plant population will not affect yields as much as might be expected. This is because most crops have a good deal of built-in buffering** capacity, especially if the population is too low. In this case, the plants respond by making yieldfavoring changes such as increased tillering (millet, sorghum) and branching (peanuts, other pulses), more pods or ears per plant or larger ears or grain heads. In maize, a plant density that is 40 percent below the optimum for the given conditions may lower yields by only 20 percent.

- Plant population changes have a more pronounced effect under conditions of moisture stress

**What is the ideal plant population?**

There is no easy answer to this, because the optimum plant density depends on several factors:

- Type of crop and variety: Because of differences in plant size and architecture, crops and their varieties vary in their tolerance to increasing plant populations. For example, early maturing maize varieties are usually

**shorter and smaller than later maturing ones and therefore may benefit from higher plant densities. Beans and cowpeas respond well to populations three to four times higher than for maize due to their smaller plant size and a growth habit that favors better light interception.**

- **Available soil moisture: The optimum plant population density varies directly with rainfall and the possibility of moisture stress. Plant population has a stronger effect on yields under low moisture conditions than when moisture is adequate. This is because increased populations also increase water use, although plant spacing can make a difference. This is particularly true for maize and sorghum, because yields can be significantly reduced by relatively small increases in plant population when grown under moisture stress.**

- **Available nutrients: Adequate soil fertility is especially essential with high plant populations. In fact, fertilizer response is often disappointing when plant populations are too low for the given conditions. In fact, this is one of** the main reasons that small farmers often do not get their money's worth out of fertilizer. An ear of maize can only grow so big, and even high rates of fertilizer can not make up for too few ears produced by a small number of plants.

- Management ability: High populations require more soil fertility and moisture as well as better overall general management.

## Plant Spacing and Its Effects on Crop Yields

The reference crops are row crops for some very good reasons. A row arrangement permits quicker and easier weeding and facilitates most other growing operations. Row cropping with its handy space for equipment, animal, and human traffic allows for ease of mechanization and handling, no matter what the level of sophistication. Distributing a given plant population over a field involves both plant spacing within the row and the distance between the rows (row width).

Plant spacing within the row: The number of seeds that need to

**be planted per meter or foot of row length depends entirely on the plant population and row widths that have been chosen according to recommendations. The main concern then becomes whether hill planting or drill planting should be used. In drill planting mechanical planters drop seeds out one at a time along the row. Small farmers who hand plant their crops usually use hill planting, sowing several seeds per hole and spacing the holes rather far apart. This reduces time and labor and also may improve seedling emergence under crusty soil conditions, but it may lower yields somewhat because of inefficient use of space and increased competition between the plants within a hill for sunlight, water, and nutrients.**

**Row Width: Space between rows is determined by the type of equipment used as well as by plant size or "spread". The use of tractor-or animal-drawn equipment requires more space between rows (wider row widths) than when only hoes and backpack sprayers are used. Beans can be spaced in narrower rows than maize or other tall crops and still be weeded with an animal-drawn cultivator without knocking the plants down. Row width influences crop yields in four ways:**

- **As row width is narrowed, the plants can be spaced farther apart within the row and still maintain the same population. Up to a point, this makes for better weed control due to earlier and more effective between-row shading by the crop.**

- **Narrower rows allow for higher plant populations without overcrowding.**

- **As row width is widened, plants have to be crowded closer together within the row in order to maintain the same population. This may lower yields.**

**Should the use of narrower rows be encouraged? Here are some things to consider:**

**1. Switching from 100 cm to 75 cm rows in maize and sorghum may increase yields by as much as 5-10 percent when total plant population is kept constant.**

**When grown alone, bush beans and bush cowpeas are ususally planted in narrow rows (45-60 cm) by most small**

**farmers. Under good management and yields, most studies have not shown much advantage to reducing peanut row width below 75-100 cm. Given the marginal moisture conditions under which millet is grown, row widths less than 75-100 cm are unlikely to be advantageous.**

**2. Row width and moisture use: Although narrower rows cut down water evaporation from the soil surface because of earlier and more complete soil shading, this is often negated by increased plant water use (transpiration) due to better leaf exposure to sunlight. Under low moisture conditions, plant population has a much greater influence on water use than row width.**

**3. It is doubtful that a 5-10 percent yield increase will have much of an influence on small farmers whose yields are fairly low. Even if yields are good, switching to narrower rows may cause more problems than it is worth:**

- **Narrow rows cost the farmer more in terms of time, seed, and pesticide. That is because the**

**narrower the row width, the greater the total amount of row length per hectare or other land unit, since there are simply more rows to deal with.**

- **If tractor-drawn equipment is used, overly narrow rows may increase plant damage from tractor tires and passing equipment as well as increase soil compaction near the row zone. If several crops are being grown under tractor cultivation, it is more convenient to settle on a standard row size rather than be constantly readjusting tire spacing, tire size, and cultivator tine spacing. Remember, too, that row width must be kept wide enough to permit tractor cultivation (weeding). This cannot be done by relying solely on herbicides!**

## Summary of Plant Population and Spacing Studies Conducted with the Reference Crops

**MAIZE: Overly high populations cause increased lodging, barren**

**stalks, unfilled ears, and small ears. Dry, husked ears weighing more than 270-310 g indicate that plant population was probably too low for the conditions and that yields might have been 10-20 percent higher. Ear size of prolific (multiple-ear) varieties will not vary as much with changes in plant density as will single-ear varieties; rather the number of ears per plant will decrease as density increases.**

**Hill versus drill planting: Numerous trials with maize have shown yield increases of 0-13 percent when drill planting (one seed per hole) was substituted for hill planting at two to three seeds per hole. However, lodging appears to be more of a problem with drill planting. Farmers who are hand planting four to six seeds per hole should be encouraged to switch to two to three seeds per hole and space the holes close enough together to achieve the desired plant population. It is doubtful that switching to drill planting is worth the extra labor involved under hand planting.**

**Under adequate moisture and fertility, optimum plant populations vary from about 40,000 to 60,000 per hectare. Plant size, management, fertility, and the varietiy's tolerance to plant**

**density and available moisture must be considered when making population changes. Studies also show that overly high populations have a negative effect on maize yields when moisture is low.**

**SORGHUM: Optimum plant population varies markedly with available water, plant height, tillering ability, and fertility. In varieties that tiller well, plant population is less important than with maize since the plants can compensate for overly low or high populations by varying the production of side shoots.**

**In West Africa, the improved long-season photosensitive and the improved short-season non-sensitive varieties are sown at the rate of 40,000-80,000/ha under good management; the dwarf photosensitive, long-season varieties are sown at rates of 100,000/ha or more.**

**All the above populations are based on monoculture.**

**PEARL MILLET: In West Africa, millet is planted in hills usually a meter or more apart; many seeds are sown per hill, and thinning**

**takes place two or three weeks later. This involves much hand labor and is seldom finished before serious competition has taken place. Trials in Upper Volta by ICRISAT showed that millet germinated best when planted at many seeds per hill and that hill planting outyielded drill planting. However, other ICRISAT work in West Africa showed no difference between yields from hill and drill plantings.**

**Population and spacing: In West Africa, pearl millets of the Gero type are often interplanted at populations of 7500-8500 plants per hectare with two to three other crops. The taller, long-season Maiwa types are sown at 40,000-80,000 plants/ha when planted alone under good management. For improved dwarf Geros, populations over l00,000/ha are recommended.**

**Most varieties have a strong tillering ability and adjust themselves to varying densities through changes in tiller production. Within limits, yields are not greatly affected by plant population changes.**

**PEANUTS: In parts of West Africa, peanuts are frequently**

**interplanted in combination with sorghum, millet, and maize. Because peanuts are the most valuable, the tendency is to keep the cereal population down to about 3000-6000 hills per hectare and the peanut density high at about 30,000 hills per hectare, or about the same as under sole cropping.**

**In West Africa, the recommended plant population for improved varieties grown alone ranges from about 45,000-100,000/ha. Rows vary from 24-36 inches (60-40 cm) and seed spacing in the row from 15-25 cm. For the Virginia types populations of 45,000-60,000/ha have been found to be optimum, with higher populations recommended for the Spanish-Valencia types.**

**Early studies in the U.S. in the 1940's and 1950's obtained yield increases of 30-40 percent by switching from row widths of 90 cm to 4560 cm. At that time, however, average yields were relatively low (1550 kg/ha). As yields have increased over the years, the importance of row width has diminished considerably, and most U.S. growers are using 75-95 cm widths with one seed every 10 cm. A stand of one plant every 15-20 cm is felt to be adequate, but overplanting is needed to make up for any losses.**

**Two new developments may influence row widths: 1) smaller-size, dwarf varieties which will not fully spread out to cover a 90 cm row width. 2) Plant growth regulators like Alar, which are internode shorteners (internodes are the spaces between nodes on the stem and branches) which decrease plant size and are especially suited to runner types.**

**BEANS: The International Center for Tropical Agriculture (CIAT) studies in Colombia have shown that bush beans grown alone give highest yields in spacings of either 30 cm between rows and 9 cm between plants 45 cm between rows and 60 cm between plants (equivalent to about 400,000 seeds/hectare). A yield plateau is usually reached around 200,000250,000 actual plants per hectare, but stand losses from planting to harvest are often in the 25-40 percent range, meaning that considerable overplanting is necessary. High density plantings also appear to increase the height of the pods from the ground, which lessens rotting problems. However, very narrow rows aggrativate Sclerotium stem rot where it occurs.**

**Studies by CIAT and the Center for Tropical Agriculture, Research**

**and Training (CATIE) indicate that plant populations for bush beans in the range of 200,000250,000/ha are also ideal when grown together with maize.**

**Trials with climbing beans show that final plant populations of 100,000-160,000/ha are optimum, whether grown alone with trellising or with maize.**

**COWPEAS: In West Africa, improved cowpea varieties of the vining type are grown at population densities ranging from 30,000100,000/ha in rows 75-100 cm apart.**

**CHICKPEAS: An ICRISAT study showed that yields remained relatively stable over wide ranges of plant density (4-100 plants per square meter).**

**Guidelines for Attaining a Good Stand and The Desired Spacing**

**Eight key factors largely determine whether a farmer actually ends up with a good stand of plants and the right spacing for the conditions:**

- **Seed-germination ability**
- **Percent of overplanting**
- **Planting depth**
- **Seedbed condition (clods, moisture, etc.)**
- **Seedbed type (flat, furrow or ridge planting)**
- **Accurate measurement when hand planting and calibration of mechanical planters**
- **Soil insects and diseases**
- **Fertilizer placement.**

**Seed-germination ability**

**Always run a germination test (see page 121 before planting; good seed should test out at close to 90 percent. Up to a point, overplanting will compensate for lower germination, but seed testing below 50 percent germination should not be used since seedling vigor is also likely to be affected.**

**Percent of Overplanting**

**No matter how well the seed germinates, the farmer should still**

**overplant to make up for any added plant losses due to insects, diseases, birds, and weeding operations. When using good seed, it is usually a sound practice to overplant by 15-20 percent in order to assure the recommended final stand of plants at harvest. Of the reference crops, beans, cowpeas and peanuts are likely to suffer the greatest plant losses and will usually benefit from even higher overplanting. Much depends on the specific growing conditions. High rates of overplanting (500 percent or more) followed by heavy hand thinning are a standard practice when field planting small vegetable seeds like cabbage, tomatoes, and lettuce. This is not recommended for the reference crops, since their seeds are larger, hardier, and more vigorous in their early growth. Labor and seed costs are excessive with high overplanting and thinning. Millet is commonly thinned in West Africa after being overplanted heavily, but this should be discouraged.**

**Planting Depth**

**Optimum planting depth varies with the crop, soil type (sandy versus clayey), and soil moisture content. Seeds should be placed**

deep enough so that moisture is available for germination, but shallow enough so that seedling emergence is not impaired. Local farmers should be regarded as the ultimate authority on the best planting depths, but here are some general guidelines:

- Seeds can be planted deeper in sandy soils than in clayey soils without reducing plant emergence.

- Planting depth should be deeper under low soil moisture conditions.

- Large seeds have more emergence strength than small ones, but this is also affected by the seedling's structure. Maize, millet, and sorghum push thorugh the soil with spikelike tips which aid emergence. Peanuts, beans, and the other pulses emerge in a much more blunt form.

## Normal Ranges in Planting Depths for the Reference Crops

| | |
|---|---|
| Maize: | 3.75-8 cm |
| Sorghum: | 3.75-6 cm |
| Millet: | 2-4 cm |

| | |
|---|---|
| Millet: | 2-4 cm |
| Peanuts, Beans, Cowpeas. | 3-8 cm |

**Seedbed condition**

**Cloddiness and soil moisture will affect germination. Some soils, especially those high in silt, tend to form a hard surface crust when drying out after a rain. This can sometimes seriously reduce emergence, especially for the pulses. If necessary, these crusts can be broken up with a spiketooth harrow or other homemade device.**

**Seeds should be in reasonably firm contact with moist soil. Most tractor-drawn planters have steel or rubber "press" wheels running behind them to help improve seed and soil contact. (See page 105 for more information on seedbed preparation.)**

**Seedbed type**

**Most of the crops can be flat-, furrow- or ridge-planted according to the particular soil and climate conditions. Good drainage and**

freedom from ponding (standing) water is especially vital for peanuts, beans, and cowpeas, which are particularly susceptible to root and stem rots. They should be flat-planted where drainage is good or sown on top of ridges or beds where drainage is poor. If flat-planting, care should be taken not to form a depression along the seed row where water could collect. This is a problem where mechanical planters with heavy press wheels are used, but can be avoided by using wider press wheels and throwing extra soil into the row ahead of the planter with cultivator sweeps.

## Planter calibration; accuracy of hand planting

Mechanical planters must be calibrated (adjusted) prior to planting to assure that they space the seeds out correctly.

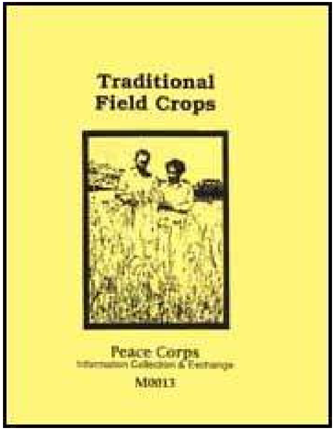
Hand planting is prone to large errors in row width and seed spacing unless some effort is made to assure accuracy. The use of a planting rope or chain along the row with knots or paint marks to indicate the spacing is recommended.

## Soil insects and diseases

**Seeds may need to be treated with a fungicide dust to help control seed rots which are especially serious under cool, wet conditions. Seed or soil treatment with an insecticide may also be needed to protect against damage from insects that attack the seeds and young seedlings.**

**Fertilizer placement**

**Fertilizer placed too close to the seeds or in contact with them may prevent or seriously reduce germination. This depends on the kind, amount, and placement of the fertilizer (see page 161).**






**Traditional Field Crops (Peace Corps, 1981, 283 p.)**

**Soil fertility and management**

**Fertilizers**

**Fertilizer use is often the management factor producing the largest increases in reference crop yields. However, yield**

**response is heavily influenced by two factors:**

- **The control of other limiting factors: Fertilizer usually gives a much better response when used as part of a "package" of improved practices designed to control other major yield limiting factors in addition to soil fertility.**

- **How fertilizer is used: Good results from fertilizer cannot be expected unless the farmer knows what kind and how much to use, and how and when to apply it.**

**Aside from water, sunlight, and air, plants need 14 mineral nutrients which are usually grouped as follows:**

**MACRONUTRIENTS**

**Primary Secondary**

| | |
|---|---|
| NITROGEN (N) | CALCIUM (Ca) |
| PHOSPHORUS (P) | MAGNESIUM (Mg) |
| POTASSIUM (K) | SULFUR (S) |

| | |
|---|---|
| MIRONUTRIENTS | (not primary or secondary) |
| IRON (Fe) | ZINC (Zn) |
| MANGANESE (Mn) | BORON (B) |
| COPPER (Cu) | MOLYBDENUM (Mo) |

**The macronutrients make up about 99 percent of a plant's diet. Nitrogen, phosphorus and potassium account for about 60 percent and are definitely the "Big Three" of soil fertility, both in terms of the quantity needed and the likelihood of deficiency (see Table 4).**

**This does not mean that the secondary macronutrients or the micronutrients are any less essential. True, their deficiencies are not as common, but they can have just as serious an effect on crop yields.**

**Table 4. Amount of Nutrients Taken Up by a 6300 kg Yield of Shelled Maize**

| Macronutrients | Kg | Micronutrients | Grams |
|---|---|---|---|
| Nitrogen | 157 | Iron | 4200 |

| | | | |
|---|---|---|---|
| Phosphorus ($P_2O_5$) | 60 | Manganese | 1000 |
| Potassium ($K_2O$) | 124 | Zinc | 30 |
| Calcium | 29 | Copper | 7 |
| Magnesium | 25 | Boron | 7 |
| Sulfur | 17 | Molybdenum | 0.7 |

**Nitrogen (N)**

**Nitrogen is the most commonly deficient nutrient for non-legumes. It promotes vegetative growth and is an essential constituent of protein and chlorophyll (needed for photosynthesis).**

**Crops vary in their need for N. Crops with a lot of vegetative (leafy) growth have relatively high N needs. These include maize, sorghum, millet, rice, sugarcane, pasture grasses, and most leafy and fruit-type vegetables. Root crops like potatoes, sweet potatoes, cassava (manioc, yuca), and tropical yams have lower N needs, and excessive amounts tend to favor leafy growth over**

**tuber growth (with the exception of most improved potato varieties which have high N needs).**

**Legumes are able to satisfy part or all of their N needs themselves through the process of nitrofixation. Peanuts, cowpeas, mung beans, pigeonpeas, and chickpeas are usually able to meet their own N requirements in this way. Common beans (kidney beans) are less efficient at N fixation and may need up to half as much N fertilizer as maize. Too much nitrogen can adversely affect crop growth, especially if other nutrients are deficient:**

- **It may delay maturity.**
- **It may lower disease resistance.**
- **It may increase lodging problems in cereal crops.**

**Available versus Unavailable N**

**Only nitrogen in the form of ammonium ($NH^{+}_{4}$) and nitrate ($NO^{-}_{3}$) in the soil is available to plants. However, about 98-99**

**percent of a soil's total N is in the unavailable organic form as part of humus. Soil microbes gradually convert this unavailable organic N into ammonium and then nitrate. Most soils are too low in humus to supply N at a rapid enough rate for good yields. That is why N fertilizer is usually needed for non-legumes.**

**Available soil N can become tied up and unavailable when crop residues low in N are plowed into the soil. This is because the soil microbes that decompose the residues need N to make body protein.**

**Most crop residues like maize, millet, and sorghum stalks supply large amounts of carbon, which the microbes use for energy, but not enough N for the microbes' protein needs. The microbes make up for this shortage by taking ammonium and nitrate N from the soil. A crop may suffer a temporary N deficiency if planted under these conditions, until the microbes finish decomposing the residues and finally release the tiedup N as they die off. (Occasionally even young legumes will be affected.) This type of N deficiency can be prevented easily by applying about 2530 kg/ha of N at planting time when growing a non-legume.**

**Available N is Easily Lost**

**Nitrate N ($NO^-_3$) is much more readily leached (carried downward away from the root zone by rainfall or irrigation) than ammonium N ($NH^+_4$), since it is not attracted to and held by the negatively charged clay and humus particles. (These act like magnets and hold onto positively charged nutrients like $NH_4^+$, $K^+$, and $Ca^{++}$ and keep them from leaching).**

**The problem is that tropical and sub-tropical temperatures are always high enough to promote a rapid conversion of ammonium N to nitrate N by soil microbes. Most ammonium type fertilizers will be completely changed to leachable nitrate in a week in warm soils. The higher the rainfall and the sandier the soil, the higher the leaching losses of N. The best way to avoid excessive leaching is to apply only part of the fertilizer at planting and the rest later on in the crop's growth when uptake is higher.**

**Phosphorus (P)**

**Phosphorus promotes root growth, flowering, fruiting and seed formation. Remember these four vital facts about phosphorus:**

- **Phosphorus deficiencies are widespread: Much of a soil's native P content is tied up and unavailable. Worse yet, only about 5-20 percent of the fertilizer P applied will be available to the crop since much of it also gets tied up as insoluble compounds. This P fixation is especially a problem on highly-weathered, red tropical soils low in pH (high in acidity).**

- **Phosphorus is virtually immobile in the soil: Phosphorus does not leach except in very sandy soils. Many farmers apply P fertilizer too shallowly and very little gets to the roots.**

- **Young seedlings need a high concentration _of P in their tissues to promote good root growth. This means that P needs to be applied at planting time. One study showed that maize seedlings take up to 22 times as much P per unit of length as do 11weekold plants.**

- **Application method is vitally important and determines how much of the added P gets tied up. Broadcast applications (uniform applications of fertilizer over the entire field) maximize P tie-up and should seldom be recommended for small farmers. Placement in a band, half-circle or hole near the seed is two to four times as effective as broadcasting, especially for low to medium rates of application.**

**Potassium (K)**

**Potassium promotes starch and sugar formation, root growth, disease resistance, stalk strength, and general plant vigor. Starch and sugar crops like sugarcane, bananas, potatoes, cassava, and sweet potatoes have particularly high K needs. Maize, sorghum, millet, rice, and other grasses are more efficient K extractors than most broadleaf crops. Remember these facts about K:**

- **Potassium deficiencies are not as common as those of N and P: Most volcanic soils tend to have good available supplies. However, only the soils lab can tell for sure.**

**Potassium: Only about one or two percent of the soil's total K is in the available form, but this is often enough to satisfy the needs of some crops. The good news is that tie-up of fertilizer K is not usually serious and never approaches that of P.**

- **Leaching losses are usually minor: The available form of K has a positive (plus) charge. The negatively charged clay and bumus particles act like magnets and attract the plus-charged K to their surfaces to help reduce leaching. However, leaching losses can be a problem on sandy soils or under very high rainfall.**

- **High K applications can encourage magnesium deficiencies.**

## The Secondary Macronutrients: Calcium (Ca), Magnesium (Mg), And Sulfur (•)

**For most crops, calcium is more important for its role as a liming material (to raise soil pH and lessen acidity) than as a nutrient.**

**Even very acid soils usually have enough calcium to meet the plants' nutrient needs, while soil pH may be too low for good growth. It takes large amounts of calcium to raise the pH compared to those needed for plant nutrition.**

**Peanuts, however, are an exception and have unusually high calcium needs which usually must be met by supplying gypsum (calcium sulfate.) This is not a liming material.**

**Magnesium deficiencies are more common than those of calcium and are most likely to occur in sandy, acid soils (usually below pH 5.5) or in response to large applications of K. Too much calcium relative to magnesium also can bring on Mg deficiencies. Farmers who need to lime their soils are usually advised to use dolomitic limestone (about a 50-50 mix of Ca and Mg carbonates). Both calcium and magnesium are slowly leached from the soil by rainfall.**

**Sulfur deficiencies are not common, but are most likely to occur under these conditions:**

- **Many volcanic soils tend to be low in available S. Land near industrial areas usually receives enough S from the air.**

- **Sandy soils and high rainfall**

- **Use of low sulfur fertilizers (see Table 17). Low analysis fertilizers (those with a relatively low NPK content) generally contain much more • than high analysis fertilizers such as 18-46-0, 0-45-0, etc.**

**The Micronutrients**

**Micronutrient deficiencies are much less common than those of N,P, or K, but are most likely to occur under these conditions:**

- **Highly leached, acid, sandy soils.**
- **Soil pH above 7.0 (except for molybdenum which is more available at lower pH's).**
- **Intensively cropped soils fertilized with macronutrients only.**
- **Areas where vegetables, legumes and fruit trees are**

**grown.**

- **Organic (peat) soils.**

**Table 5 Susceptibility of the Reference Crops to Micronutrient Deficiencies**

| Crop | Most Common Micronutrient Deficiency | Conditions Favoring Deficiency |
|---|---|---|
| MAIZE | Zinc | Soil pH above 6.8; sandy soils; high P |
| SORGHUM | Iron | Soil pH above 6.8; sandy soils; high P |
| BEANS | Manganese, Zinc | Soil pH above 6.8; sandy soils |
| | Boron | Acid, sandy soils, pH above 6.8 |
| PEANUTS | Manganese, Boron | Refer to above |

**Micronutrient Toxicities: Iron, manganese and aluminum can become overly soluble and toxic to plants in very acid soils.**

Boron and molybdenum can cause toxicities if improperly applied.

## Determining fertilizer needs

The amount of nutrients that different crops must absorb from the soil to produce a given yield is fairly well known. Yet proper fertilization is not a simple matter of adding this amount for several reasons:

- The farmer needs to know what share of the nutrients are already in the soil in available form.

- A plant's ability to recover nutrients, whether from fertilizer or natural soil sources, depends on the type of crop, the particular soil's capacity to tie up different nutrients, weather conditions (sunlight, rainfall, temperature), leaching losses, physical soil factors like drainage and compaction, and insect and disease problems.

Likewise, there is no such thing as "tomato fertilizer" or "maize fertilizer", etc. Soils differ so much in natural fertility that no one

**fertilizer could possibly be right for all types of soil, even for one kind of crop.**

**When dealing with the reference crops, farmers cannot afford to waste their scarce capital on fertilizers that might be inappropriate for their soils. They also need reasonable guidelines on how much to apply. There are five basic methods used to determine fertilizer needs:**

- **Soil testing**
- **Plant tissue testing**
- **Fertilizer trials**
- **Spotting visual "hunger signs"**
- **Making an educated guess**

## Soil Testing

**Soil testing by a reliable laboratory is the most accurate and convenient method for determining fertilizer rates.**

**Most labs routinely test for available P and K and measure soil pH and exchange capacity (the soil's negative charge). Most do not**

**test for available N, since results are not very accurate.**

**Some will be able to test for Ca, Mg, S, and some of the micronutrients (micronutrient and • tests vary in reliability).**

**If the soil is overly acid, the lab will usually be able to tell how much lime the soil will need. Most can test the salinity and alkali hazard of the soil and irrigation water (most common in semi-arid to arid areas).**

**At the very least, the lab will provide an N-P-K application recommendation for the crop involved The better labs will tailor the recommendation of the farmer's yield goal and management ability, based on the farmer's responses to a questionnaire supplied by the lab.**

**Portable soil test kits are not as accurate as laboratory testing but can give a fairly good estimate of soil conditions at a test site. The instructions state within what limits the test kit is accurate.**

**These kits give results that are as accurate as most farmers will need for growing reference crops. However, if a soil testing**

**laboratory is available farmers should be encouraged to send samples in. How to Take a Soil Sample**

**Improper sampling by the farmer or extension worker is the most common cause of faulty lab results. A 200-400 gram sample may represent up to 15,000 tons of soil. The soil laboratory's instructions should be carefully read before sampling. These are usually printed on the sampling box or on a separate sheet. (See Appendix J for general instructions on how, when, and how often to soil test.)**

**Plant Tissue Tests**

**The crop can be tissue-tested while growing in the field for N-P-K levels in the sap. Kits cost about US $20-$42, but some of the reagents need replacement every year.**

**Tissue tests are best used to supplement soil test data, since the results can be tricky to interpret by non-professionals. Sometimes plant sap nutrient levels are not well correlated to those in the soil, because weather extremes, insects, and**

**diseases affect uptake. Deficiencies of one nutrient such as N can stunt plant size and cause P and K to "pile up: in the plant sap, giving falsely high readings. The tests are also geared to higher yield levels than most small farmers can reasonably hope to attain. The crops receiving low to moderate fertilizer rates that provide the best return per dollar may show tissue test results indicating deficiencies.**

**One advantage of tissue testing is that it may be possible to correct a deficiency while the crop is still growing and thus increase yields.**

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

**When collecting leaf samples, it is important to pay close attention to the kit's or lab's sampling instructions. Taking leaves from the wrong part of the plant will make results invalid.**

**Fertilizer Trials**
**See Chapter 8 and Appendix B.**

## Spotting Visual "Hunger Signs"

**Severe nutrient deficiencies usually produce characteristic changes in plant appearance, particularly in color. Spotting these "hunger signs" can be useful in determining fertilizer needs, but there are several drawbacks:**

- **Some hunger signs are easily confused with each other or with insect and disease problems. If more than one nutrient is deficient at once, the hunger signs may be too vague for accurate diagnosis.**

- **Hidden hunger: Hunger signs will not usually appear until the nutrient deficiency is serious enough to cut yields by 30-60 percent or more. This "hidden hunger" can cause unnecessarily low yields even though the crop may look good throughout the growing season.**

- **It may be too late to correct deficiencies by the time hunger signs appear. Any N applied much beyond flowering time in the cereal crops will increase grain** protein more than yields (such protein increases are slight compared to the amount of N used and the yield that is sacrificed by late application). Phosphorus should ideally be placed 7.5-10 cm deep and this is difficult to do without damaging the roots after the crop is up and growing.

Specific hunger signs for the reference crops may be found in Appendix G.

**Making an Educated Guess**

If no soil test results are available for a farmer's field, a reasonable estimate of N-P-K needs can be made based on at least four or more of the following criteria:

- Available soil test results from nearby farms with the same soil type and a similar liming and fertilizer history.

- Data from fertilizer trials on the same soil type.

- An extension pamphlet on the crop with fertilizer recommendations for the area soils. (Do not rely on their accuracy unless the recommendations are based on soil tests and/or field trial results.)

- The particular crop's relative nutrient needs (discussed later in this section).

- A thorough examination of the soil for depth, drainage, texture, filth, slope, and other factors that may limit yields or fertilizer response, including soil pH (see page 169 on liming).

- Yield history and past management of the farm regarding fertilizer and liming.

- The farmer's management ability, available capital, and willingness to use complementary practices like improved seed, insect control, etc.

## Fertilizer types and how to use them

Chemical (inorganic) fertilizers are frequently accused of everything from "poisoning" the soil to producing less tasty and

**nutritious food. Should the extension worker encourage client farmers to forget about chemical fertilizers and use only organic ones (compost, manure)? The "organic way" is basically very sound, because organic matter (in the form of humus) can add nutrients to the soil and markedly improve soil physical condition (filth, waterholding capacity) and nutrientholding ability. Unfortunately, some misleading and illusory claims on both sides of the issue cause a lot of confusion.**

**Chemical fertilizers supply only nutrients and exert no beneficial effects on soil physical condition. Organic fertilizers do both. However, compost and manure are very low-strength fertilizers; 100kg of 10-5-10 chemical fertilizer contains about the same amount of NP-K as 2000 kg of average farm manure. The organic fertilizers need to be applied at very high rates (about 20,000-40,000 kg/ha per year) to make up for their low nutrient content and to supply enough humus to measurably imrpove soil physical condition.**

**Overwhelming evidence indicates that chemical and organic fertilizers work best together. A study at the Maryland**

**Agricultural Experiment Station (U.S) showed a 2033 percent yield increase when chemical fertilizers and organic matter were applied together, compared with applying double the amount of either alone.**

**Most small farmers will not have access to enough manure or other organic matter to cover more than a small portion of their land adequately. When supplies are limited, they should not be spread too thinly and are often most effective on high-value crops (such as vegetables) grown intensively on small plots.**

**Manure**

**Fertilizer value: Animal manure is an excellent source of organic matter, but relatively low in nutrients. The actual fertilizer value depends largely on the type of animal, quality of the diet, kind and amount of bedding used, and how the manure is stored and applied. Poultry and sheep manure usually have a higher nutrient value than horse, pig or cattle manure. Constant exposure to sunlight and rainfall will drastically reduce manure's fertilizer value.**

**On the average, farm manure contains about 5.0 kg N, 2.5 kg $P_2O_5$, and 5.0 kg $K_2O$ per metric ton (1000 kg), along with various amounts of the other nutrients. This works out to a 0.5-0.25-0.5 fertilizer formula. (See the chemical fertilizer section for an explanation of how fertilizer ratios are determined if this is confusing.) BUT only about 50 percent of the N, 20 percent of the P, and 50 percent of the K is readily available to plants during the first month or two, because most of the nutrients are in the organic form which first has to be converted to the available inorganic form by soil microbes. This does mean, however, that manure has good residual fertilizer value.**

**Farm manure is low in phosphorus: It tends to have too little available P in relation to available N and K. If used as the sole source of fertilizer, some experts recommend fortifying it with 25-30 kg of single superphosphate (0-20-0) per 1000 kg of manure. This also helps reduce the loss of N as ammonia. However, it is more convenient and effective to apply chemical fertilizer directly to the soil instead of attempting to mix it with the manure. Manure as a source of micronutrients: When livestock such as pigs and chickens are fed largely on**

**nutritionallybalanced commercial feeds, their manure may be a particularly good source of micronutrients if applied at a high rate. Manure from animals fed mainly on local vegetation is likely to have a lower micronutrient content. How to store manure: It is best to store it under a roof or in a covered pit, but manure can be stored in piles with steep sides to shed water and good depth to reduce leaching losses by rain.**

**Guidelines for applying manure:**

- **Manure is best applied a couple of weeks to a few days before planting. If applied too far in advance, some N may be lost by leaching. To avoid "burning" the crop seeds and seedlings, fresh manure should be applied at least a couple of weeks in advance; rotted manure is unlikely to cause damage.**

- **Manure containing large amounts of straw may actually cause a temporary N deficiency unless some fertilizer N is added.**

- **Manure should be plowed, disked or hoed under soon after application. A delay of just one day may cause a 25 percent loss of N as ammonia gas.**

- **Rates of 20,000-40,000 kg/ha are generally recommended, but limit poultry and sheep manure to about 10,000 kg/ha since it is more likely to cause "burning". This works out to about 2-4 kg/sq. m ( 1 kg/sq. m for poultry and sheep manure).**

- **If quantities are limited, farmers are better off using moderate rates over a larger area rather than a high rate on a small area.**

- **Manure also can be applied in strips or slots centered over the row if farmers are willing to make the extraeffort involved. This is a good way to use scarce amounts. Fresh manure may burn seeds or seedlings if not mixed well with the soil.**

## Compost

As with manure, large amounts are needed to improve soil physical condition or supply meaningful amounts of nutrients. Compost-making takes a tremendous amount of labor and is seldom feasible for anything but small garden plots. (For more information on compost, refer to the PC/ICE Soils, Crops, and Fertilizer Use manual.)

## Other Organic Fertilizers

Blood meal and cottonseed meal have much higher N contents than manure and compost, and contain other nutrients as well. However, they are valued as animal feeds and are likely to be too expensive. Bone meal (15-20 percent $P_2O_5$ ) makes P available very slowly and is also expensive.

The hulls of rice, cotton-seed, and peanuts have virtually no nutrient value, but can be used as mulches or to loosen up clayey soils on small plots. They may cause a temporary N tie-up.

## Green Manure Crops

See Chapter 4, page 94.

## Chemical fertilizers

**Chemical fertilizers (also called "commercial or "inorganic" fertilizers) contain a much higher concentration of nutrients than manure or compost, but lack their soil-improving qualities.**

**Few farmers will have enough organic fertilizer to cover more than a fraction of their land adequately, so chemical fertilizers are usually an essential ingredient for improving yields quickly. Despite their ever-increasing cost, they can still frequently return good value if correctly used.**

### Types of Chemical Fertilizers

**For soil application, granules are the most commonly used form. They usually contain one or more of the "Big Three" (N, P, K), varying amounts of sulfur and calcium (as carriers), and very low or nonexistent amounts of micronutrients.**

**The fertilizers can be either simple mechanical mixes of two or more fertilizers or an actual chemical combination with every granule identical in nutrient content.**

## How to Read a Fertilizer Label

**All reputable commercial fertilizers carry a label stating their nutrient content, not only of NP-K, but also of any significant amounts of sulfur, magnesium, and micronutrients. The Three Number System: This states the content of NP-K in that order, usually in the form of N, $P_2O_5$, and $K_2O$. The numbers always refer to percent. A 12-24-12 fertilizer contains 12 percent N, 24 percent $P_2O_5$, and 12 percent $K_2O$ which is the same as 12 kg N, 24 kg $P_2O_5$ and 12 kg $K_2O$ per 100 kg. A 0-21-1 fertilizer has no nitrogen or potassium, but contains 21 percent $P_2O_5$. Here are some more examples:**

- **300 kg 16-20-0 contain 48 kg N, 60 kg $P_2O_5$ 0 kg $K_2O$**
- **250 kg 12-18-6 contain 30 kg N, 45 kg $P_2O_5$ 0 kg $K_2O$**

## The Fertilizer Ratio

**The fertilizer ratio refers to the fertilizer's relative proportions of K, $P_2O_5$ and $K_2O$. A 12 24-12 fertilizer has a 1:2:1 ratio and so**

**does 6-12-6; it would take 200 kg of 6-12-6 to supply the same amount of N-P-K as 100 kg of 12-24-12. Both 15-15-15 and 10-10-10 have a 1:1:1 ratio. N, $P_2O_5$, $K_2O$ versus N, P, K: Note that a fertilizer's N content is expressed as N, but that the P and K content is usually expressed as $P_2O_5$ and $K_2O$. This system dates back to the advent of chemical fertilizers in the 19th Century and is still used by most countries, although a few have switched to an NP-K basis. A fertilizer recommendation given in terms of "actual P" and "actual K", refers to the new system; check the fertilizer label to see if the nutrient content is given as N-$P_2O_5$ -$K_2O$ or as N-P-K.**

**The formulas below show how to con vert between the 2 systems:**

**$P \times 2.3 = P_2O_5$**
**$P_2O_5 \times 0.44 = P$**
**$K \times 1.2 = K_2O$**
**$K_2O \times 0.83 = K$**

**For example, a fertilizer with a 14-14-14 N-$P_2O_5$-$K_2O$ label would be labeled 14-6.2-11.6 on an N-P-K basis. Likewise, if a fertilizer recommendation calls for applying 20 kg of "actual P" per hectare, it would take 46 kg (i.e. 20 2.3) of $P_2O_5$ to supply this amount. Table 6 gives the nutrient content of common fertilizers. (Refer to pages 74-78 of PC/ICE'S Soil, Crops and Fertilizer Use manual for more detailed information.)**

**Basic guidelines for applving chemical fertilizers**

**Nitrogen**

**When fertilizing maize, sorghum, and millet, one-third to one-half of the total N should be applied at planting time. This first application will usually be in the form of an N-P or N-P-K fertilizer. The remaining N should be applied in one to two sidedressings (fertilizer applications made along the row while the crop is growing) later on in the growing season when the plants' N usage has increased. A straight N fertilizer like urea (4546 percent N), ammonium sulfate (2021 percent N) or ammonium nitrate (33-34 percent N) is recommended for**

**sidedressings. When one sidedressing is to be made, it is usually best applied when the crops are about knee-high (25-35 days after plant emergence in warm areas). On very sandy soils or under high rainfall, two sidedressings may be needed and are best applied at the knee-high and flowering stages.**

| NITROGEN SOURCES | N % | $P_2O_5$ % | $K_2O$ % | S % |
|---|---|---|---|---|
| Anhydrous ammonia ($NH_3$) | 82% | 0 | 0 | 0 |
| Ammonium nitrate | 33% | 0 | 0 | 0 |
| Ammonium nitrate with lime | 20.5% | 0 | 0 | 0 |
| Ammonium sulfate | 20-21% | 0 | 0 | 23-24% |
| Ammonium phosphate | 16% | 20% | 0 | 9-15% |
| sulfate (2 types) | 13% | 39% | 0 | 7% |
| Mono-ammonium phosphate | 11% | 48% | 0 | 3-4% |
| (2 kinds) | 12% | 61% | 0 | 0 |
| Di-ammonium phosphate | 16% | 48% | 0 | 0 |
| (3 kinds) | 18% | 46% | 0 | 0 |
| | 21% | 53% | 0 | 0 |
| Calcium nitrate | 15.5% | 0 | 0 | 0 |
| Sodium nitrate | 16% | 0 | 0 | 0 |

| | | | | |
|---|---|---|---|---|
| Potassium nitrate | 13% | 0 | 46% | 0 |
| Urea | 45-46% | 0 | 0 | 0 |
| PHOSPHORUS SOURCES | | | | |
| Single superphosphate | 0 | 16-22% | 0 | 8-12% |
| Triple superphosphate | 0 | 42-47% | 0 | 1-3% |
| Mono-& di-ammonium phosphates (see under N) | | | | |
| Ammonium phosphate sulfate (see under N) | | | | |
| POTASSIUM SOURCES | | | | |
| Potassium chloride (muriate of potash) | 0 | 0 | 62% | 0 |
| Potassium sulfate | 0 | 0 | 50-53% | 18% |
| Potassium nitrate | 13% | 0 | 44% | 0 |
| Potassium magnesium sulfate (11% Mg, 18% MgO) | 0 | 0 | 21-22% | 18% |

NOTE: $P_2O_5$ X 0.44 = P; $K_2O$ X 0.83 = K; S X 3.0 = $SO_4$

**Table 6 Composition of common fertilizers**

## Table 6 COMPOSITION OF COMMON FERTILIZERS

| **NITROGEN SOURCES** | **N %** | **$P_2O_5$** | **$K_2O$ %** | **S %** |
|---|---|---|---|---|
| Anhydrous ammonia ($NH_3$) | 82% | 0 | 0 | 0 |
| Ammonium nitrate | 33% | 0 | 0 | 0 |
| Ammonium nitrate with lime | 20.5% | 0 | 0 | 0 |
| Ammonium sulfate | 20-21% | 0 | 0 | 23-24 |
| Ammonium phosphate | 16% | 20% | 0 | 9-15 |
| sulfate (2 types) | 13% | 39% | 0 | 7 |
| Mono-ammonium phosphate | 11% | 48% | 0 | 3-4 |
| (2 kinds) | 12% | 61% | 0 | 0 |
| Di-ammonium phosphate | 16% | 48% | 0 | 0 |
| (3 kinds) | 18% | 46% | 0 | 0 |
| | 21% | 53% | 0 | 0 |
| Calcium nitrate | 15.5% | 0 | 0 | 0 |
| Sodium nitrate | 16% | 0 | 0 | 0 |
| Potassium nitrate | 13% | 0 | 46% | 0 |

| | | | | |
|---|---|---|---|---|
| Urea | 45-46% | 0 | 0 | 0 |
| **PHOSPHORUS SOURCES** | | | | |
| Single superphosphate | 0 | 16-22% | 0 | 8-12 |
| Triple superphosphate | 0 | 42-47% | 0 | 1-3 |
| Mono-& all-ammonium phosphates (see under N) | | | | |
| Ammonium phosphate sulfate (see under N) | | | | |
| **POTASSIUM SOURCES** | | | | |
| Potassium chloride | 0 | 0 | 62% | 0 |
| (muriate of potash) | | | | |
| Potassium sulfate | 0 | 0 | 50-53% | 18% |
| Potassium nitrate | 13% | 0 | 44% | 0 |

| | | | | |
|---|---|---|---|---|
| Potassium magnesium | 0 | 0 | 21-22% | 18% |
| sulfate (11% Mg, 18% MgO) | | | | |

**NOTE: $P_2O_5$ X 0.44 = P; $K_2O$ X 0.83 = K; S X 3.0 = $SO_4$**

**Where to Place Nitrogen Fertilizer**

**As an N-P or NP-K Fertilizer: See the section on phosphorus below. As an N Sidedressing: There is no need to place a straight N fertilizer as deep as with P and K, since rainfall will carry the N downward into the root zone. Work it in 1.0-2.0 cm to keep the fertilizer from being carried away by surface water flow. Urea should always be worked in to avoid loss of N as ammonia gas. (The same is true for all ammonium N fertilizers when soil pH is above 7.0')The best time to sidedress is right before a weeding (cultivation)- the cultivator or hoe can then work it into the soil a bit.**

**Nitrogen can be placed in a continuous band along the crop row 20 cm or more out from the plants. Crops with spreading root**

**systems like maize, sorghum, and millet can be sidedressed mid-way between the rows with no loss of effect. There is no need to broadcast the N to encourage better distribution, because it will spread outward as it moves downward through the soil. Avoid spilling fertilizer on the crop leaves since it can burn them. (Fertilizer burn occurs when too much fertilizer is deposited too close to the seeds or seedlings, causing them to turn brown and lose ability to absorb water.) If time is short, every other row can be sidedressed with twice the per-row amount.**

**Phosphorus**

**Phosphorus is virtually immobile in the soil. This means that fertilizers containing P should be placed at least 7.5-10 cm deep to assure good root uptake. The roots of most crops are not very active close to the soil surface (unless some form of mulching is used) since the soil dries out so readily. For these reasons, all the P fertilizer should be applied at planting time:**

- **Young seedlings need a high concentration of P in their tissues for good early growth and root development.**

- **Phosphorus does not leach, so there is no need to make additional sidedressings.**

- **To be effective as a sidedressing, P would also need to be placed deep (except on a heavily mulched soil), and this might damage the roots.**

**NOTE: Many farmers waste money by sidedressing with N-P, N-P-K or P fertilizers after already applying P at planting. Others do not apply P until the crop is several weeks old. In either case, crop yields suffer.**

**How to Minimize Phosphorus Tie-up**

**Only about 5-20 percent of the fertilizer P that the farmer applies will actually become available to the growing crop. Application method has a big influence on the amount of tie-up that occurs. In general, farmers should not broadcast fertilizers containing P, even if they plow or hoe them into the ground. Broadcasting maximizes P tie-up by spreading the fertilizer too sparsely and exposing each granule to full soil contact. Broadcasting gives a**

**much better distribution of P throughout the topsoil, but very high rates are needed to overcome tie-up and few small farmers can afford them. In fact, it takes about two to ten times as much broadcast P to produce the same effect as an equal amount of locally placed P. Instead, farmers should use one of the localized placement methods described below. Concentrating the fertilizer in a small area enables it to overcome the tie-up capacity of the immediate surrounding soil.**

**Adding large amounts of organic matter to the soil helps decrease P tie-up, but usually is not feasible on large fields. Soil pH should be maintained within the 5.57.0 range if possible. Very acid soils have an especially high P tie-up capacity. When P is applied as an N-P or N-P-K fertilizer, the N helps increase the uptake of P by the plant roots.**

**Placement of P Fertilizers**

**Continuous band method: This is the best method for the reference crops and is especially well suited to closely spaced drill plantings. The optimum location of the band is 5.0-6.0 cm to**

**the side of the seed row and 5.0-7.5 cm below seed level. One band per row is sufficient.**

**How to make a band: The farmer has a couple of choices:**

**a. Fertilizer band applicators are available for most models of tractor drawn planters and for some animal-drawn planters. Handpushed band applicators are also available commercially. The International Institute for Tropical Agriculture (IITA) farming systems program has designed a hand-pushed model that can be built in any small workshop with welding and metal shearing capabilities. However, it is not clear from the design whether the IITA model actually places the fertilizer below the soil surface.**

**b. Plow or hoe methods**

- **The farmer can make a furrow 7.5-15 cm deep with a wooden plow or hoe, apply the fertilizer by hand along the bottom, then kick in enough soil to fill the furrow back up to planting depth. This gives a band of fertilizer running** under the seeds and a little to each side. As long as there is 5.0-7.5 cm of soil separating the fertilizer and the seeds, there is little danger of burning.

- A less satisfactory method is to make one furrow at planting depth and place both seed and fertilizer in it together (the furrow should be wide so the fertilizer can be spread out and diluted somewhat). This works with maize at low to medium rates of N and K (no more than 200-250 kg/ha of 16-20-0 or 14-1414, no more than 100-125 kg ha of 18-460 or 16-48-0). Higher rates may cause fertilizer burn. Beans and sorghum are more sensitive to fertilizer burn than maize. Halfcircle Method: Works well when seeds are planted in groups ("hill planting") spaced relatively far apart on untilled ground where banding would be impractical. The fertilizer is placed in a half circle made with a machete, hoe, or trowel about 7.5-10 cm away from each seed group and 7.5-10 cm deep. This is time-consuming, but gives a better distribution of fertilizer than the hole method. Hole method: This is the least effective of the three methods, but is much better than using no fertilizer at all. It may be the only feasible method for land that has been hill planted without any prior tillage. Fertilizer is placed in hole 10-15 cm deep and 7.5-10 cm away from each seed group.

**Potassium**

**Potassium ranks midway between N and P in terms of leaching losses. As with P, all the K can usually be applied at planting time, often as part of an N-P-K fertilizer. Where leaching losses are likely to be high (very sandy soils or very high rainfall), split applications of K are sometimes recommended.**

**Unlike N and P, about twothirds of the K that plants extract from the soil ends up in the leaves and stalks rather than in the grain. Returning crop residues to the soil is a good way of recycling K. Burning them will not destroy the K, but will result in the loss of their N, sulfur, and organic matter.**

**Some Special Advice For Furrow-Irrigated Soils**

**When using the band, halfcircle or hole methods on furrow**

**irrigated soils (crops irrigated by conveying water along a furrow between each row or bed) the farmer should be sure to place the fertilizer below the level that the irrigation water will reach in the furrow. Placement below this "high water" mark enables mobile nutrients like nitrate and sulfate to move sideways and downwards toward the roots. If placed above the water line, the upward capillary movement of water will carry these mobile nutrients to the soil surface where they cannot be used. (Upward capillary movement is the same process that enables kerosene to "climb" up the wick in a lamp.)**

**Determining how much fertilizer to use**

**The following table can be used to determine how much fertilizer to apply per length of row (if the half-circle or hole method is used). (The formula found in PC/ICE's Soil, Crops and Fertilizer Use manual can also be used to determine this amount.)**

**NOTE: Rather than tell farmers to apply so many grams or ounces per length of row or per hill, convert the weight dosage to a volume dosage using a commonly available container like a tuna**

**fish or juice can, jar lid or bottle cap.**

**Fertilizers vary in density, so be sure to determine the weight/ volume relationship for each type using an accurate scale.**

I. Per Meter of Row Length (For band applications):

| | AMOUNT OF FERTILIZER NEEDED PER HECTARE | | | | | |
|---|---|---|---|---|---|---|
| Row | 100 kg | 200 kg | 300 kg | 400 kg | 500 kg | 600 kg |
| Width | GRAMS TO APPLY PER METER OF ROW LENGTH | | | | | |
| 50 cm | 5 | 10 | 15 | 20 | 25 | 30 |
| 60 cm | 6 | 12 | 18 | 24 | 30 | 36 |
| 70 cm | 7 | 14 | 21 | 28 | 35 | 42 |
| 80 cm | 8 | 16 | 24 | 32 | 40 | 48 |
| 90 cm | 9 | 18 | 27 | 36 | 45 | 54 |
| 100 cm | 10 | 20 | 30 | 40 | 50 | 60 |

**Table 7 Determining How Much Fertilizer is Needed per Meter of Row Length or per "Hill"**

**II. Per Hill (For half-circle or hole applications): In this case, the**

**amount depends on the row spacing and the distance between hills in the row. The table below shows how many grams of fertilizer are needed per hill to equal a rate of 100 kg/ha. To find out how much would be needed to equal a rate of 250 kg/ha, you would multiply the table's figures by 2.5.**

| Row | 30 cm | 40 cm | 50 cm | 60 cm | 70 cm | 80 cm | 90 cm | 100 cm |
|---|---|---|---|---|---|---|---|---|
| Width | GRAMS OF FERTILIZER NEEDED PER HILL TO EQUAL 100 KG/HA | | | | | | | |
| 50 cm | 1.5 | 2.0 | 2.5 | 3.0 | 3.5 | 4.0 | 4.5 | 5.0 |
| 60 cm | 1.8 | 2.4 | 3.0 | 3.6 | 4.2 | 4.8 | 5.4 | 6.0 |
| 70 cm | 2.1 | 2.8 | 3.5 | 4.2 | 4.9 | 5.6 | 6.3 | 7.0 |
| 80 cm | 2.4 | 3.2 | 4.0 | 4.8 | 5.6 | 6.4 | 7.2 | 8.0 |
| 90 cm | 2.7 | 3.6 | 4.5 | 5.4 | 6.3 | 7.2 | 8.1 | 9.0 |
| 100 cm | 3.0 | 4.0 | 5.0 | 6.0 | 7.0 | 8.0 | 9.0 | 10.0 |

**Distance between hills**

## Foliar Fertilizers

**Foliar applications are best suited for micronutrients: Soluble powder or liquid fertilizers may be sold in some areas for mixing**

**with water and spraying on the leaves. Some granular fertilizers like urea, ammonium nitrate, and di-amonium phosphate are also soluble enough for this purpose. However, only small amounts of fertilizer can be sprayed on the leaves per application without causing "burning" - this means that foliar applications are usually best suited for micornutrients of which very little is needed. Foliar applications are especially useful for applying iron, which becomes readily tied up and unavailable when applied to the soil. Although foliarapplied fertilizers take effect rapidly (within one to three days) they have much less residual value than soil applications.**

**N-P-K foliar fertilizer are often claimed to produce very profitable yield increases.**

- **Numerous trials have shown that N-P-K foliar fertilizers usually "green up" the leaves but significant yield increases are unlikely as long as sufficient N-P-K is applied to the soil. A 1976 International Center for Tropical Agriculture (CIAT) trial in Colombia did obtain a 225 kg/ha yield increase on beans by spraying them three**

**times with a 2.4 percent solution (by weight) of mono-ammonium phosphate (11-480) even though 150 kg/ha of $P_2O_5$ had been added to the soil. (The spray contributed only about 10 kg/ha of $P_2O_5$.) However, the soil had a very high P tie-up capacity.**

**The soluble powder and liquid foliar fertilizers are much more expensive per unit of nutrient compared to ordinary granular fertilizers.**

**Numerous applications are usually needed to supply a meaningful amount of N-P-K through the leaves without risk of burning.**

**Some N-P-K foliar fertilizers have micornutrients included but the amounts are far too small for preventing or curing deficiencies.**

## How to Avoid Fertilizer "Burn"

**Fertilizer "burn" occurs when too much fertilizer is placed too**

**close to the seeds or seedlings. It is caused by a high concentration of soluble salts around the seed or roots which prevents them from absorbing water. The seeds may germinate poorly from tips downward, the seedling leaves may begin to turn brown, and the plants may die.**

**Guidelines for Avoiding Fertilizer Burn**

- **The N and K in fertilizers have a much higher "burning" ability than P. Single and triple superphosphate are very safe. Sodium nitrate and potassium nitrate have the highest burn potential per unit of plant nutrient followed by ammonium sulfate, ammonium nitrate, monoammonium phosphate (11-48-0), and potassium chloride. Di-ammonium phosphate (16-48-0, 18-46-0) and urea can injure seeds and seedlings by releasing free ammonia gas. The higher the ratio of N and K to P in an N-P-K fertilizer, the greater the likelihood of burning due to improper placement.**

- **When using fertilizers containing N, do not place them** any closer than 5 cm to the side of the seed row when banding and 7.5 cm when using the half-circle or hole methods (see exceptions discussed under banding methods). There is little danger of burning when sidedressing growing crops with N, but avoid dropping the granules on the leaves.

- Fertilizer burn occurs more frequently on sandy soils than on clayey soils and under low moisture conditions. A heavy rain or irrigation will help carry damaging salts away if burning occurs.

## Recommended fertilizer rates for the reference crops

The most profitable rate of fertilizer use for the small farmer depends on management ability, capital available, limiting factors, soil fertility level, type of crop, expected price and cost of fertilizer.

Small farmers should usually aim for maximum return per dollar spent. This means using low to moderate rates of fertilizer

**because crop yield response is subject to the law of diminishing returns.**

**Since the efficiency of fertilizer response declines as rates go up, the small farmer with limited capital is usually better off applying low to medium rates of fertilizer. He or she will end up with a higher return per dollar invested, be able to fertilize more land, and have money left over to invest in other complementary yield-improving practices.**

**As a farmer's capital situation improves, higher rates of fertilizer may be justified as long as investments in other worthwhile practices are not sacrificed. Another factor to consider is that fertilizer can reduce the land and labor needed to produce a given amount of crop, thus cutting costs and allowing for more diversity of production.**

## Some General Guidelines for Low, Medium and High Rates Of N-P-K

**Keeping in mind the many factors that determine optimum**

**fertilizer rates, Table 8 provides a very general guide to LOW, MEDIUM, and HIGH rates of the "Big Three" for the reference crops based on small farmer conditions and using localized placement of P. The "high" rates given here would be considered only low to medium by most farmers in Europe and the U.S. where applications of 200 kg/ha of N are not uncommon on maize and irrigated sorghum.**

**There are several important qualifications to Table 8:**

- **YOU MUST CONSIDER THE FERTIILITY LEVEL OF THE SOIL as well as the type of crop. A soil high in available K would need little or no fertilizer K. Most cropped soils tend to be low in N and low to medium in P, but K deficiencies are less common. Peanuts often respond better to residual P and K rather than to direct applications.**

- **Legumes such as peanuts, cowpeas, soybeans, pigeonpeas, mung beans, and chickpeas are very efficient N fixers if properly innoculated with the correct strain of Rhizobia bacteria or if grown on soils with a good natural**

**population of the correct Rhizobia. In some cases, however, a starter application of 15-25 kg/ha of N has given a positive response by feeding the plants until the Rhizobia begin to fix N (about two to three weeks after plant emergence). Such responses are the exception rather than the rule and are most likely to occur on sandy soils. Beans (Phaseolus vulgaris) are not so efficient at N fixation and can use up to 50-60 kg/ha of N.**

- **The farmer's management ability is a vital consideration. Farmers should not be encouraged to use a high rate of fertilizer if he or she is not willing or able to use other complementary yieldimproving practices.**

**Table 8 General guidelines for low, medium, and high rates of N-P-K**

| | **LOW (Lbs./acre or kg/hectare)** | **MEDIUM(Lbs./acre or kg/hectare)** | **HIGH(Lbs./acre or kg/hectare)** |
|---|---|---|---|
| N² | 35-55 | 60-90 | 100+ |

| | | | |
|---|---|---|---|
| $P_2O_5$ | 25-35 | 40-60 | 70+ |
| $K_2O$ | 30-40 | 50-70 | 80+ |

**Fertilizer recommendations for specific crops**

**Maize**

**Fertilizer Response**

**When starting from a low yield base like 1000-1500 kg/ha, yields of shelled maize should increase by roughly 25-50 kg for each kg of N applied up to a yield of around 40005000 kg/ha. With higher rates of application, response generally falls below this ratio. Such yield increases will be obtained if:**

- **Other nutrients like P and K are supplied as needed, soil moisture is adequate, a responsive variety is used, and there are no serious limiting factors such as insects, diseases, weeds, soil ph, drainage, etc.**

- **The fertilizers are applied correctly and at the right time.**

**If response falls velow the 25-50 level, this means that one or more serious limiting factors is present or that too high an N rate was used. Table 8 can be used as a guide, but soil should be tested whenever possible. Studies have shown that maize can use locally-placed (band, half-circle, hole) P efficiently up to about 50-60 kg/ha of $P_2O_5$.**

**Micronutrients: Except for zinc, maize is not very susceptible to micronutrient deficiencies. Zinc deficiency can be confirmed by spraying about 20 plants with a solution of one tablespoon (15 cc) zinc sulfate in about four liters of water along with about 5 cc of liquid dishwashing detergent as a wetting agent. If zinc is the only nutrient lacking, new leaves will have a normal green color when they emerge.**

**Table 9**

| Zinc Source | % Zinc | Amount Needed | Application Method |
|---|---|---|---|
| Zinc sulfate | 23% | 8-12 kg/ha (lbs./acre) | mixed with planting fertilizer |

| | | | |
|---|---|---|---|
| monohydrate | | | and locally placed |
| Zinc sulfate heptahydrate | 35% | 6-9 kg/ha (lbs./acre) | mixed with planting fertilizer and locally placed |
| Zinc oxide | 78% | 2.5-4 kg/ha (lbs./acre) | mixed with planting fertilizer and locally placed |
| Zinc sulfate | 23%, 35% | 350-500 grams/100 liters water plus a wetting agent | Foliar; spray the leaves; may cause leaf burn under some conditions. |

**Sorghum**

**Fertilizer Response: Sorghum will give similar fertilizer responses to maize if moisture is adequate and improved varieties are used. As always, farmers should be encouraged to test the soil first rather than rely on general recommendations.**

**Nutrient needs are similar to those of maize, except that sorghum is most susceptible to iron deficiency.**

**Iron deficiencies seldom respond well to iron applied in the soil**

**unless special chelated (organic and more costly) forms are used to protect against tie-up. Deficiencies should be treated by spraying the plants with a solution of 2-2.5 kg of ferrous sulfate dissolved in 100 liters of water along with sufficient wetting agent to assure uniform leaf coverage. Begin spraying as soon as symptoms appear; the plant may need several applications during the growing season on severely deficient soils.**

**Sorghum seeds and seedlings are more sensitive to fertilizer burn than maize. If more than one grain harvest is to be taken from one planting, all the P and K should be applied at planting along with about 30-50 kg/ha of N. Another dressing of 30-50 kg/ha of N should be applied about 30 days later. After the first harvest, apply an additional 30-50 kg/ha 25-30 days later.**

**Millet**

**Fertilizer Response: Low soil moisture is a major factor limiting fertilizer response. Traditional varieties are usually less responsive. Studies in India by ICRISAT showed that improved pearl millet varieties were responsive to N rates as high as 160**

**kg/hectare under adequate moisture, but that traditional types seldom responded well above the 4080 kg/hectare range. The N-P-K rates in Table 8 can be used as a guide, taking into consideration the moisture and variety factors.**

**Peanuts**

**Fertilizer Response: Peanuts tend to give rather unpredictable responses to fertilizer and offer respond best to residual fertility from previous applications to other crops in the rotation.**

**Nitrogen and Nodulation: If the right strain of Rhizobia bacteria is present, peanuts can ordinarily satisfy their own N requirements. There are two exceptions:**

- **If poorly drained portions of the field become waterlogged temporarily, the Rhizobia may die off and the plants begin to turn yellow. An application of 20-40 kg/ha of N may be needed to carry the plants through until the bacteria become reestablished in several weeks.**

- **In some cases (mainly on lightcolored, sandy soils), 20-**

**30 kg/ ha of N applied at planting has seemed to help the plants establish themselves until the Rhizobia begin to fix N about three weeks after emergence. This is not widely recommended.**

**To check for proper nodulation, carefully remove the roots of plants at least three weeks old and look for clusters of fleshy nodules (up to the size of small peas) especially around the tap root. Slice a few open - if they are reddish inside, this shows they are actively fixing N.**

**Seed innoculation is normally not necessary if peanuts are sown on land that has grown peanuts, cowpeas, lima beans, mung beans or crotalaria within the past three years. Commercial innoculant is a dark-colored, dried powder which contains the living Rhizobia and comes in a sealed packet. Seed is placed in a basin and moistened with water to help the innoculant stick (adding a bit of molasses helps, too). The correct amount of innoculant is mixed with the seed, and planted within a few hours. Exposing the seed to sunlight can kill the bacteria.**

**Phosphorus and Potassium: Because peanuts have an unusually good ability to utilize residual fertilizer from preceding crops, they do not respond well to direct applications of P and K unless levels are very low. In fact, there is good evidence that high K levels in the podding zone can increase the number of pops (unfilled kernels) due to decreased calcium availability.**

**Calcium: Peanuts are one of the few crops having a high Ca requirement. Light green plants plus a high percentage of pops may indicate Ca hunger. Calcium does not move from the plant to thepods; rather, each pod has to absorb its own requirement. Gypsum (calcium sulfate) is used to supply Ca to peanuts because it is much more soluble than lime and has no effect on soil pH (using lime to supply Ca can easily raise the pH too much). The usual application where deficiencies exist is 600-800 kg/ ha of dry gypsum applied right over the center of the crop row (it will not "burn") in a band 40-45 cm wide any time from planting until flowering.**

**Gypsum also supplies sulfur. Micronutrients: Boron and manganese are the ones most likely to be deficient (see Table 5).**

**Boron can be toxic if applied at rates much above those given in Table 10 especially when banded.**

## Table 10 Suggested Boron (B) and Manganese (MN) Rates For Peanuts on Deficient Soils

| Material | % B or Mn | Amount Needed | How Applied |
|---|---|---|---|
| Borax | 11% B | 5-10 kg/ha | Mixed with fungicide dusts for leafspot or mixed with gypsum. Do not locally place boron or injury may result. |
| Solubor | 20% B | 2.75 kg/ha | Spray plants |
| Manganese sulfate | 26-28% Mn | 15-20 kg/ha | Banded with row fertilizer at planting |
| Soluble manganese sulfate | 26-28% Mn | 5 kg/ha | Spray on plant leaves; use wetting agent. |

| | | | |
|---|---|---|---|
| Manganese sulfate | 26-28% Mn | 15 kg/ha | Dust the plants with the finely ground form |

**Beans (Kidney Beans)**

**Nitrogen: Beans are less efficient N fixers than peanuts or cowpeas and recommended N rates usually fall in the range of 40-80 kg/ha N. In a 1974 CIAT trial in Colombia, 40 kg/ha N increased yields to 1450 kg/ha compared to 960 kg/ha with no N. It was found that acid forming fertilizer N sources such as urea and ammonium sulfate could increase the chances of aluminum and manganese toxity if banded near the row on very acid soils. It was recommended that the N be spread out more in these cases.**

**Phosphorus: Beans have a high P requirement, and this is often the major limiting nutrient, especially on soils with a high capacity to tie up P. A 1974 CIAT trial on such a soil resulted in yields of 700 kg/ha without P and 1800 kg/ha when 200 kg/ ha of $P_2O_5$ was banded along the row. Such high rates of P may be**

**needed on soils with serious P tie-up problems. Under such conditions, it might take 10 times this amount to give the same effect if broadcast.**

**Potassium deficiencies are uncommon in beans.**

**Magnesium deficiency may occur in very acid soils or those high in Ca and K. It can be controlled by applying 100-200 kg/ha of magnesium sulfate or 20-30 kg/ha or magnesium oxide to the soil. If the soil needs liming, using dolomitic limestone (2045 percent Mg) will solve the problem. Dolomitic limestone and magnesium oxide should be broadcast and plowed or hoed under before planting. Magnesium sulfate (epsom slats) can be band-applied or sidedressed. A foliar application of one kg magnesium sulfate per 100 liters water can be tried on established crops.**

**Micronutrients: Beans are most susceptible to manganese, zinc, and boron deficiencies (see Table 5). Varieties differ in their susceptibilities. Zinc rates: As for maize. Manganese: As for peanuts. Boron: 10 kg/ha of borax banded with the row fertilizer at planting or 1 kg Solubor (20 percent B) per 100 liters of water**

**sprayed on plants. Manganese toxicity is sometimes a problem on very acid soils, especially if they are poorly drained. Symptoms are easily confused with those of zinc and magnesium deficiency. Beans are also very sensitive to aluminum toxicity which occurs below a pH of 5.2-5.5, and liming the soil is the only control. If aluminum toxicity is severe, plants may die shortly after emergence. In more moderate cases, the lower leaves become uniformly yellow with dead margins, the plants become stunted, and yields can be lowered dramatically.**

**Cowpeas**

**Well-nodulated cowpeas do not respond to N applications, although a starter dosage of 10 kg/ha N sometimes shows results.**

**Liming**

**Soils with a pH below 5.0-5.5 (depending on the soil) can adversely affect crop growth in four ways:**

- **Aluminum, manganese, and iron toxicities: These three** elements increase in sulubility as soil pH drops and may actually become toxic to plants at pH's below 5.0-5.5. Beans are especially sensitive to aluminum toxicity which is the crop's biggest yield limiting factor in some areas. Many soils labs routinely test for soluble aluminum levels in very acid samples. Manganese and iron toxicities can be serious, too, but usually are not a problem unless the soil is also poorly drained.

- Very acid soils are usually low in available P and have a high capacity to tie up added P by forming insoluble compounds with iron and aluminum.

- Although very acid soils usually have enough calcium to supply plant needs (except for peanuts), they are likely to be low in magnesium and available sulfur and molybaenum.

- Low soil pH depresses the activities of many beneficial soil microbes such as those that convert unavailable N, P, and S to available mineral forms.

**Maize and cowpeas may tolerate soil acidity in the pH 5.0-5.5 range depending on the soil's soluble aluminum content. Sorghum is somewhat more tolerant than maize to soil acidity. Peanuts commonly do well down to pH 4.8-5.0 since they have comparatively good aluminum tolerance. Beans are the most sensitive of the reference crops to soil acidity, and yields usually decline below a soil pH of 5.3-5.5.**

**Where are Acid Soils Likely To be Found?**

**Soils in higher rainfall areas are likely to be slightly acid to strongly acid since a good deal of calcium and magnesium may have been leached out over time by rainfall. Those of drier regions are likely to be alkaline or only slightly acid due to less leaching.**

**Continual use of nitrogen fertilizers, whether chemical or organic will eventually lower soil pH enough to require liming. Calcium nitrate, potassium nitrate, and sodium nitrate are the only exceptions and are usually too expensive or unavailable.**

## How to Tell if Liming is Needed

**Soil pH can be measured fairly accurately right in the field with a liquid indicator kit or a portable electric tester. These are useful for troubleshooting but have two drawbacks:**

- **Soil ph is not the sole criteria for determining if liming is needed. The soil's content of soluble aluminum (called "exchangeable" aluminum) is probably even more important, and the portable pH kits cannot measure this. A soil with a pH of 5.0 or even lower might still be satisfactory for the growth of most crops if its exchangeable aluminum content is low. On the other hand, another soil with a pH of 5.3 might need liming because of too much aluminum. Only the soils lab can tell for sure.**

- **The amount of lime needed to raise soil pH one unit varies greatly with the type of soil involved. One soil may require 810 times more lime than another to achieve the same rise in pH even though both have the same initial pH. The amount of lime needed depends on the soil's amount**

**of negative charge which varies with its texture, type of clay minerals, and amount of humus. Only the soils lab can determine this.**

## Calculating the Amount of Lime Needed

**Whether using the lab's or other recommendations, adjustments still must be made for the fineness, purity, and neutralizing value of the material used:**

- **Neutralizing value: On a more pure basis, here are the neutralizing values of four liming materials:**

| **Material** | **Neutralizing Value (compared to limestone)** |
|---|---|
| Limestone (calcium carbonate) | 100 percent |
| Dolomitic limestone (Ca + Mg carbonate) | 109 percent |
| Hydrated lime (calcium hydroxide) | 136 percent |

| | |
|---|---|
| Burned lime (calcium oxide) | 179 percent |

**This means that 2000 kg of burned lime has about the same effect on pH as 3580 kg of limestone of equal purity (2000 kg x 1.79 = 3580 kg).**

- **Fineness of material greatly affects the speed of its reaction with the soil. Even finely ground material may take two to six months to affect soil pH.**

- **Purity: Unless the material has a label guarantee, it is difficult to judge purity without a lab analysis.**

## How, When, and How Often To Lime

- **Lime should be broadcast uniformly over the soil and then thoroughly mixed into the top 15-20 cm by plowing or hoeing. Harrowing alone will only move the material down about half this distance. A disk plow or moldboard plow should be used, not a wooden or chisel plow. If spreading lime by hand, the amount should be divided in**

**half and one portion applied lenghtwise and the other widthwise. Wear a mask hydrated (slaked) lime and burned lime can cause severe burns.**

- **Whenever possible, a dolomitic form of liming material should be used to avoid creating a magnesium deficiency.**

- **Liming materials should be applied at least two to six months ahead of planting, especially if the material is not well ground.**

- **Liming may be needed every two to five years on some soils, especially if high rates of nitrogen fertilizers, manure or compost are used. Sandy soils will need more frequent liming than clayey soils since they have less buffering capacity, but sandy soils also will require lower rates.**

**DO NOT OVERLIME'**

- **Never raise the pH of soil above 6.5 when liming.**

- **Never raise the pH by more than one full unit at a time** (i.e. from 4.6 to 4.6, etc.). It is only necessary to raise the pH up to 5.5-6.0 for good yields of an aluminum sensitive crop like beans.

**Overliming can be worse than not liming at all for several reasons:**

- **Raising the pH above 6.5 increases the likelihood of micronutrient deficiencies, especially iron, manganese, and zinc; molybdenum is an exception.**

- **Phosphorus availability starts declining once pH rises much above 6.5 due to the formation of relatively insoluble calcium and magnesium compounds.**

- **Liming stimulates the activity of soil microbes and increases the loss of soil organic matter by decomposition.**

## Water management

## Water Needs of The Reference Crops

**Relative Differences: Millet has the best drought resistance of the three cereals, followed by sorghum, and then maize. Of the pulses, cowpeas and peanuts are superior to common beans in this respect. Critical Water Demand Periods: The critical water demand period for all the reference crops in terms of both yield effect and maximum usage occurs from flowering time through the soft-dough grain stage. Under low humidity and high heat, total water usage (soil evaporation and plant transpiration) may reach 910 mm per day during flowering and early grain filling. Effect of Moisture Stress on Yields: Crops can often overcome the effects of moisture stress occurring early in the season, but yields can be markedly lowered if it occurs during flowering and grain filling. With maize one to two days of wilting during tasseling time can lower yields by up to 22 percent and six to eight days by 50 percent.**

**Symptoms of Moisture Stress**

- **Maize, sorghum, and millit will begin to roll their leaves up lengthwise, and the plants will turn a bluish green color. The lower leaves will often dry up and die. (This is**

**referred to as "firing" and is really a drought-induced nitrogen deficiency.)**

- **The pulse crops will also turn a bluish-green and Their leaves will wilt as stress increases. "Firing" may also occur.**

**Factors Influencing the Likelihood of Moisture Stress:**

- **Rainfall pattern and quantity: See the section on rainfall in Chapter 2.**

- **Soil texture: This has a big influence on a soil's water storage capacity. Clay loams and clay soils can hold twice as much available water per foot of depth as sandy soils.**

- **Soil Depth: Deep soils can store more water than shallow soils and allow greater rooting depth for utilizing it.**

- **Soil Slope: Much water can be lost by runoff on sloping soils.**

- **Temperature, Humidity, and Wind: The higher the temperature and wind and the lower the humidity, the greater the rate of crop moisture use and soil evaporation losses.**

## Keeping Rainfall Records

**Since rainfall amount and distribution have such a great effect on crop yields, it is very useful to keep rainfall records at various locations in your work area. The more progressive client farmers should be encouraged to keep their own records. Judging Rainfall: Showers that produce less than 6 mm usually contribute little moisture to the crop since they do not penetrate the soil very deeply and are quickly evaporated. For example, 5 mm of rainfall will penetrate only about 20 mm into a dry clayey soil and 40 mm into a dry sandy soil.**

## Improving Water Use Efficiency

**In areas with short rainy seasons, the use of early maturing varieties is a valuable tactic. Planting dates should be timed so**

**that likely moisture stress periods do not coincide with critical crop stages such as pollination.**

**One study in Kenya showed a yield decrease of 5-6 percent for each day's delay in maize planting after the start of the rains (in an area with a short season). In areas having wet seasons of adequate length, but with periods of moisture stress, some extension services recommend planting two or more varieties with different maturities to lower the risk of total crop failure.**

**On sloping soils, soil conservation measures such as terracing or ditch-and-bank systems will significantly improve water retention in addition to reducing soil losses. Weed control both during and between crops will cut water use. In semiarid areas such as the Sahel, deep plowing should be avoided if the subsoil is moist. Fertilizer use will increase moisture use efficiency by encouraging deeper rooting. However, crops cannot utilize as much fertilizer (especially N) when water is a limiting factor.**

**Optimum plant populations are usually lower under conditions of low rainfall and probable moisture stress.**

**Mulching the soil surface with a 5.0-7.5 mm layer of crop residues can substantially increase yields in drier areas.**

**Guidelines for Improving Water Use Efficiency Under Furrow Irrigation**

**To avoid falling behind in crop irrigation needs, the soil should be pre-irrigated to the full depth of maximum expected root development before planting the crop. Moisture stored in the subsoil is usually safe from evaporation losses unless the soil cracks upon drying. Leaching losses will be negligible if the correct amount is applied since only excess water moves downward by the force of gravity - the rest is held by the soil pores.**

**Frequent, shallow irrigation should be avoided since it increases evaporation losses and limits the depth of root growth. Shallow irrigation encourages the buildup of harmful salts in dry climates, and frequent irrigation favors the spread of fungal and bacterial diseases. However, irrigation may have to be fairly frequent in the initial stages of crop growth until the plants have been able to**

**put their roots down sufficiently.**