GUIDE FOR FIELD CROPS IN THE TROPICS AND THE SUBTROPICS

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Technical Assistance Bureau
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GUIDE FOR FIELD CROPS IN THE TROPICS AND THE SUBTROPICS

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Special appreciation is also expressed to the secretarial and typing staff - Joyce Freeman, Alisare Greenwood and Cleo Leppo - without whose assistance this book would not have been possible.

FOREWORD

In the tropical and subtropical areas of the world, food grains make up the bulk of the diet for most people. Food grains together with fiber and specialty crops are also principal cash producers. It is with these commodities that this Guide for Field Crops in the Tropics and Subtropics concerns itself. The Guide deals with general situations; local applications are beyond the range of this moderate-size volume, but the basic information presented will permit area-by-area adaptations.

The Guide is designed for use by foreign assistance personnel and cooperators. It is specifically directed to the programs of the U.S. Agency for International Development (USAID) Missions, working with country governments. The text is written in layman's language because it is not only the specialists in these crops who are called upon for information about them. Questions come also to nonspecialists and specialists in other fields such as national leaders and advisers, members of the Peace Corps and of international companies, missionaries, teachers, research workers and students. Information on the subject may be found in scientific literature, textbooks and other documents, but finding a compilation of current information in ready reference form is rare.

This concise, up-to-date Guide is composed of 40 chapters. The first four are general introductory chapters, and treat rather extensively the important subjects of climate, soil, cropping, and farming systems as related to the tropics and subtropics. The other 36 chapters are divided as follows: 6 on cereal crops, 9 on food legumes, 6 on oil crops, 7 on root or tuber crops and bananas, 6 on major fiber crops and 2 on other cash crops. These chapters do not attempt to deal with the factors of providing inputs such as national supplies of fertilizer, insecticides and fungicides.

The very important subjects of credit and marketing are not covered and, at the most, only brief mention is made of the ultimate utilization of the crops. This Guide covers only the physical and biological aspects of production with the intent of providing a sound base for the application of the economic and social factors that are needed for healthy agricultural development.

Leon F. Hesser

Leon F. Hesser
Acting Director
Office of Agriculture
Bureau for Technical Assistance

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CHAPTER 1

INTRODUCTION [1]

This Field Guide is offered as a convenient aid to achieving more efficient production of selected crops in less developed countries of the tropics and subtropics. It is specifically oriented toward the small farmer rather than toward plantation agriculture. This is partly because it is the small farmers in the aggregate that will continue to produce most of the foods for total consumption in each nation, by both rural and urban sectors. Also, the rural populations of these countries account for 50 to 90% of the total national population, and it is imperative that there be a significant increase in rural income, and in the distribution of that income. Efficient production of food crops and of crops for cash sales are a prime method for advancing the rural economy and the quality of rural living. This is not to belittle the goals of industrialization and other means of developing natural resources for national advancement. Rather, rural development in balance with urban growth, industrialization and commerce, appears to be a basic requirement for each nation's advancement. A major method for creating better opportunities for the great numbers of small farmers and their families is by producing crops more efficiently to meet family food needs and to provide cash crops for meeting other family needs.

Meeting Food Needs

How important is it to developing nations that they meet growing food needs; and what role does the small farmer fill in total food production?

World population is growing at the rate of 2.6% yearly, and by 1985 it is estimated that total population increase will amount to 2 billion people. It is predicted that 2/3 of that increase will occur in less developed nations located in the tropics and subtropics. It has been estimated by FAO that world food production must increase by at least 140% by 1985 (above 1965) to avoid the specter of recurring widespread famines. Obviously, in each tropical and subtropical nation increased food production must equal population growth to prevent a worsening of the present food situation; and a still larger increase is needed to alleviate present areas of distress in the available amounts of food, and to produce diets that are much better balanced in proteins, minerals and vitamins. Further, substantial increases

[1] Edited by C.A. Breitenbach, Regional Rural Development Officer, Latin American Bureau, Agency for International Development, Washington, D. C. 20523

in crop production are needed to provide surpluses that will permit the small farmer to enter the cash economy, to make possible his acquisition of better clothing, housing, sanitation and medical services, education and communications.

The outlook is not gloomy. The successes with "Miracle" rice emanating from the International Rice Research Institute (IRRI) in the Philippines, and "Mexican" wheat from the International Center for Wheat and Maize Improvement (CIMMYT) in Mexico, clearly demonstrate that great advances are possible. Improved production of these two crops in a relatively few large nations has meant that food production has more than kept pace with food needs in those countries, thus reversing a long struggle. The extension of the basic lessons learned with rice and wheat, to the other major food crops, and to other crops grown in rotations for cash sales, could transform the economic status of the developing nations and the welfare of their rural populations.

Improved Nutrition

Special attention must be given to the problem of protein malnutrition that is widespread in the tropics and subtropics. Malnutrition resulting from a deficiency in total calories is the most obvious problem in any region; but protein malnutrition is even more serious and more difficult to combat than simple hunger. Protein malnutrition is most serious with weaned infants, pregnant women and nursing mothers and younger school age children. Deprivation may affect development of the central nervous system as well as body size, creating generations of a weakened people.

Total protein is in even shorter supply in the tropics and subtropics than energy foods, and much less has been done in providing more protein foods. The outlook for real advances in the production of animal proteins (meat, milk, eggs, fish) to correct current deficiencies in total protein supply, and to keep pace with growing populations, is not encouraging. Much of the increased protein to balance human diets must come from protein rich crops, including eight major food grain legumes, (beans, peas, chickpeas, lentils, mungbeans, pigeon peas, broad beans, cowpeas) groundnuts, and soybeans and the oil seed crops -- cottonseed, sesame, sunflowers, and safflower. These are tropical and subtropical crops, and they could well serve as profitable cash crops, as well as sources of dietary proteins. All of these crops can be made much more productive than at present; they store well and can serve as staple foods for urban people to a much greater extent than they now do. Chapters are provided on each of these crops.

Considerable progress has been made in the genetic improvement of the nutritional value of crops since the discovery in 1964 by Purdue University scientists that the opaque-2 gene in maize not only materially increases the content of the two amino acids, lysine and tryptophan, but it greatly increases the nutritional value over that of normal maize. Opaque-2 grain for example fed to monogastric animals results in weight gains several times that obtained with normal maize. Today maize breeding researchers throughout the world are supporting programs to develop opaque-2 hybrids or varieties as its nutritive value has been demonstrated to be equally superior for humans. More recently two Ethiopian lines of sorghum were found at Purdue which exhibit the same superior biological feeding value as that of opaque-2 maize. Not only are these lines high in the nutritionally-limiting amino acid lysine but they are much higher in protein as well as low in tannin, a factor which has been found to be responsible for reduced protein digestibility in the sorghum grain. In the case of wheat, Nebraska University is regularly incorporating the "Atlas" gene for increased protein (about 25%) into their best commercial types. Further improvement in protein content with no proportionate loss in lysines is expected from new derivatives from other genetic sources used as parents. Similar improvements in protein content of rice varieties have been obtained at IRRI in the Philippines as have been obtained with wheat. At the University of Illinois, they have discovered that the industrial soybean can be prepared at the home or village level, resulting in a product essentially equal in consistency and acceptance to that of the bean and at least twice as nutritious. The development of a man-made crop called triticale in Mexico by an international team of scientists at CIMMYT from a cross of wheat with rye also offers promise for improving the nutritional value of the resulting grain over that obtainable from wheat by having higher protein and lysine content. With barley, high lysine lines have been isolated by European scientists and these are now being employed by leading scientists to improve the nutritional value of commercial types all over the world.

Utilization of Natural Resources

The agriculture of every nation is based on its land and soil resources, its climate, and the natural vegetation which serves as an index of agricultural productivity, as well as on the skills of its rural people in using these resources for production of crops and livestock. Crop production offers great versatility that can be exploited by choosing crop types adapted to the various climatic regions and soil types, and invoking those management practices that give the greatest returns for the inputs and the labor that are applied. Crop production must fill an appropriate role in use of natural resources, in conjunction with animal agriculture, forestry, and wildlife and game. Wherever crop production provides the best utilization of soil and climatic resources, of the various alternative uses, it should receive the full application of modern science and technology to make the selected crops as productive as feasible. To make wise choices, it is desirable to know for each crop, its natural adaptations, its present uses and potential yielding power, the characteristics of the plant, and possible improved varieties and cultural practices to achieve greater efficiency of production.

In each of the 36 chapters on specific crops, attention is given to the conditions of climate and soil needed for successful production of each crop and the cultural practices that will best utilize these natural resources. This information is intended to aid in evaluating the potential value of alternative crops to fit the conditions in specific regions, and to guide the selection of crop species with the greatest promise. This information also should be useful in planning crop rotations, and the choice of crops that fit a chosen farming system for inclusion in each years operations. General information on the individual crops may serve in the planning of farming systems that more adequately utilize modern agricultural science and technology.

Serving the Small Farmer

In undertaking to indicate how new technology will improve the efficiency of crop production, emphasis is placed on the methods that are feasible for the small farmer. To be most useful, practices should be labor intensive rather than capital intensive, whenever economically practicable, so as to provide greater employment of rural populations. The intent is to aid each man in becoming more productive, by making more certain that his efforts result in higher yields for the time applied to each crop. This objective is wholly compatible with higher crop yields per hectare, and with greater returns for every unit of fertilizer or other inputs used in production.

Application of Technology to Local Farming

It is recognized that the generalized treatments of crop production offered in each chapter, do not include much detailed information needed for specific regions. It is hoped that this field guide may serve primarily as a framework, which may be expanded by extension specialists within each country, to provide the detailed recommendations for application of new technology by local farmers.

Moving Products to the Consumer

Recognition should be given to the need for supplemental effort by governments and businesses, to support the flow of inputs to the growers, and to improve the entire system of marketing, from the point of delivery of crops by the grower, to purchase by the ultimate consumer, or to the export centers. Increased volume of production and more efficient harvest will not by themselves produce benefits to either the growers or to the national economy, unless parallel improvements are made in collecting, storing, processing, distributing, and retailing of the crops grown. The grower should be recognized as a cooperator in development of the national economy, and given equal recognition and protection with processors and marketers by the government as it seeks to improve agricultural productivity and efficiency. Unless early attention is given to the entire marketing process, improved crop production may have little value to either the individual grower or to the nation.

CHAPTER 2

THE TROPICAL ENVIRONMENT FOR CROP PRODUCTION [1]

The need to increase crop production for growing populations, involves either expanding the land areas used for cropping, or improving the productivity of present farmland. Both will be necessary, and the successes achieved will depend on an understanding of what is feasible with present-day technology.

The basic environmental factors that determine land capability are land forms, soil conditions, and the climatic pattern of temperature and rainfall. The native vegetation zones are a convenient index of the potential of regions for specific uses, since these zones are the product of land, soil and climate. However, crop production is feasible in nearly all environmental combinations, either by choice of crops that are adapted, or by modification of the present limiting factors of the environment, such as use of fertilizers to correct deficiencies in soil fertility, adapting farming systems to conserve rainfall, irrigation in dry regions and seasons, adjusting the cropping season to the predicted length of the "rainy" season, etc.

The present production of crops has changed greatly from the pattern that prevailed 100 years ago, or 50, or even 25 years ago. The changes have been greatest in those regions where the most agricultural research has been done, and where the fruits of such research have been applied in improved technology. The most obvious changes have been the introduction of "new" crops into various tropical regions, such as the wider use made of bananas, potatoes, and maize, to name but a few. However, the very recent development of improved technology such as that created for "Miracle" rice, and "Mexican" type wheats, has been a powerful stimulant to all countries where these particular innovations are adopted: These examples may become the forerunners of great advances in the whole range of crops. These advances may involve (1) a more complete understanding of each crop and its adaptation to the regional environment, (2) the essential research on plant breeding, pest control, modification of cultural practices including time of planting and use of fertilizers, and harvesting practices and (3) associated programs of pricing and marketing. All of the basic factors that produced the "green revolution" with rice and wheat, should be studied for other food crops and the associated cash crops that fit into farming systems. This chapter outlines the general aspects of tropical and subtropical

[1] Edited by C.A. Breitenbach, Regional Rural Development Officer, Latin American Bureau, Agency for International Development, Washington, D. C. 20523

environments that have direct application to crop production, and suggests matters that affect individual crops.

The climates of the tropics and subtropics are shown in figure 1, and the duration of the arid seasons is shown in figure 1a. The basic factors that characterize these zones are the temperatures resulting from their geographic position in the tropical latitudes, or adjoining latitudes; and the modification of temperatures caused by land forms, particularly altitude, since higher altitudes generally reduce ground temperatures, and increase rainfall in the direction of air mass movement (winds).

The Climates of the Tropics and Subtropics[1] are classified as follows (figure 1);

A. <u>Climate of the tropics</u>

- V. 1. Tropical rainy climates.
- V. 2. Tropical humid summer climates.
- V. 2a. Tropical humid summer climates, with humid winters.
- V. 3. Wet-dry tropical climates.
- V. 4. Tropical dry climates.
- V. 4a. Tropical dry climates, with humid winters.
- V. 5. Tropical semidesert and desert climates.

B. <u>Climates of subtropical and warm temperate zones.</u>

- IV. 1. Dry summer - humid winter, Mediterranean zones.
- IV. 2. Dry summer steppe* climate, with humid winters.
- IV. 3. Steppe* climate with short summer humidity.
- IV. 4. Dry winter climates, with long summer humidity.
- IV. 5. Semidesert and desert climates.
- IV. 6. Permanently humid grassland climate.
- IV. 7. Permanently humid climates with hot summers.

The duration of the arid seasons in the tropics[2] is presented in figure 1a, as follows:

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(1) From "Seasonal Climates of the Earth" by C. Troll and K. H. Paffen, 1966. Pub. by Springer-Verlag.

*Note: Steppe Climates include subhumid zones (savannas) and semiarid zones (sahelian regions).

(2) Map by David R. Harris, Pub. in American Scientist. Mar. - April 1972.

(Discussion of figure 1a, "Duration of Arid Seasons," continues on page 12.)

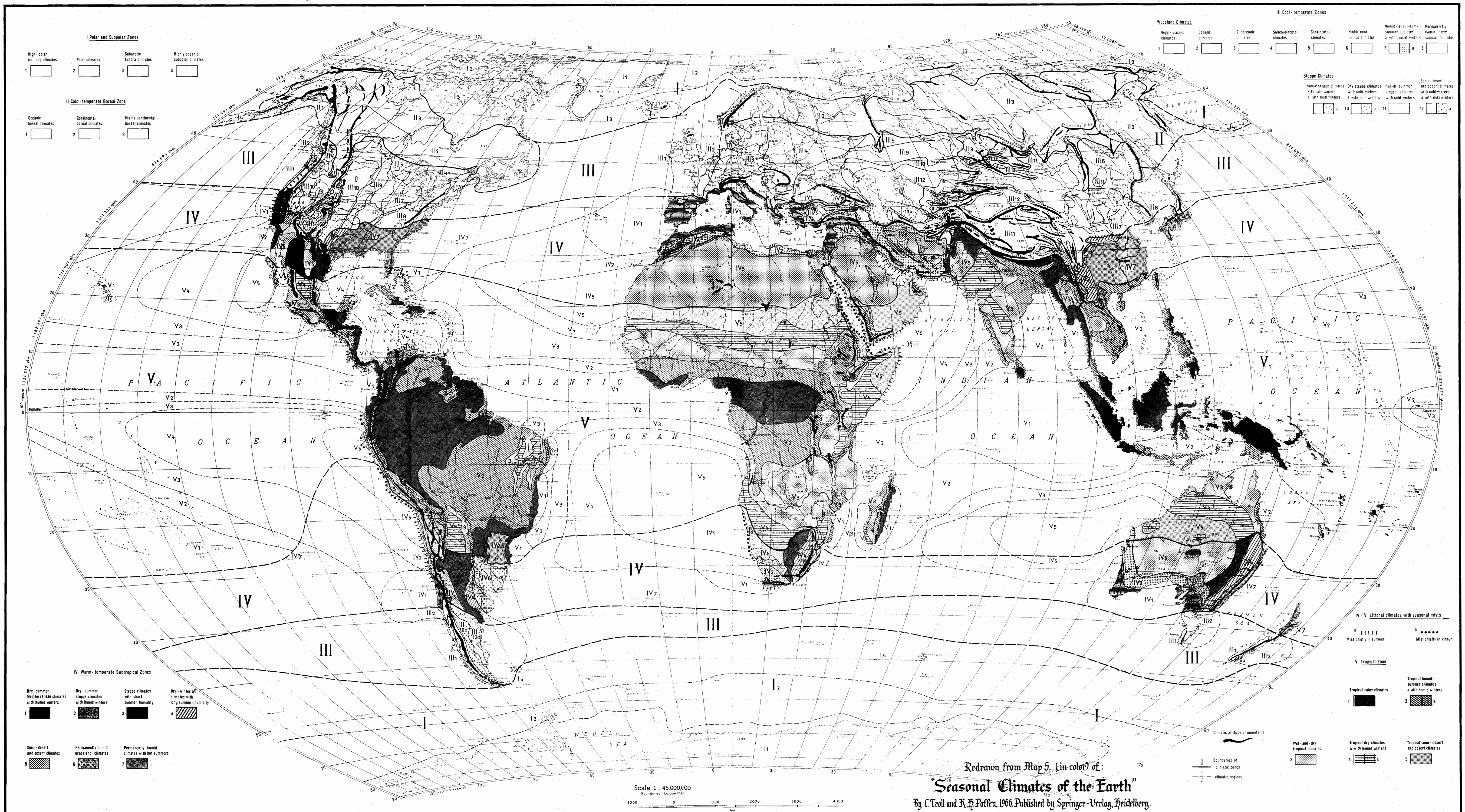

Figure 1

Hammers flächentreue Projektion mit Pollinis von K. Wagner

Weltkarten zur Klimakunde / World Maps of Climatology Springer Verlag Berlin · Göttingen · Heidelberg

Produced by FALK-VERLAG, Hamburg

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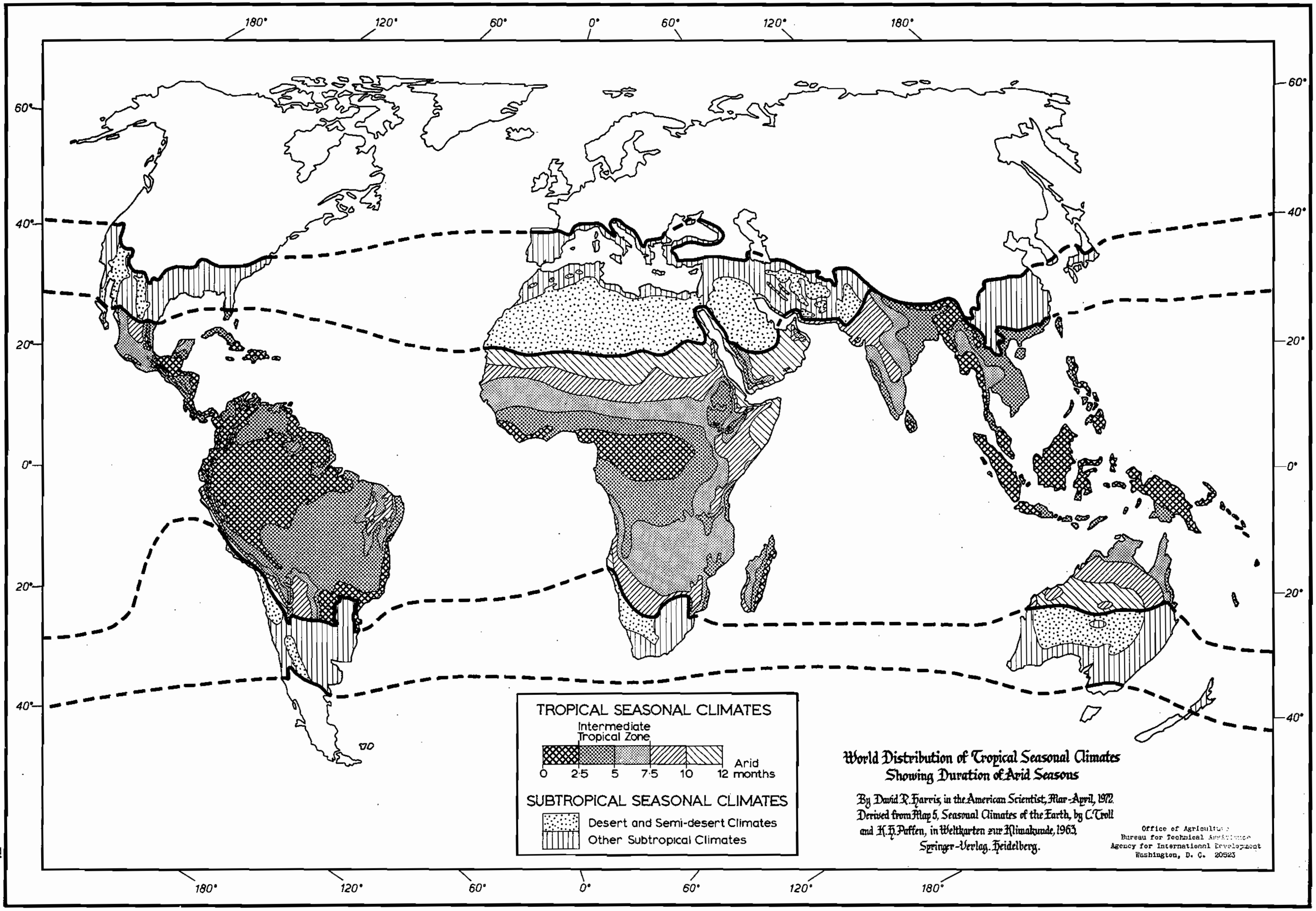

180°
120°
60°
0°
60°
120°
180°
60°
40°
20°
0°
20°
40°
TROPICAL SEASONAL CLIMATES
Intermediate Tropical Zone
0 2·5 5 7·5 10 12
Arid months
SUBTROPICAL SEASONAL CLIMATES
Desert and Semi-desert Climates
Other Subtropical Climates
World Distribution of Tropical Seasonal Climates
Showing Duration of Arid Seasons
By David R. Harris, in the American Scientist, Mar-April, 1972.
Derived from Map 5, Seasonal Climates of the Earth, by C. Troll
and K. H. Paffen, in Weltkarten zur Klimakunde, 1963.
Springer-Verlag, Heidelberg.
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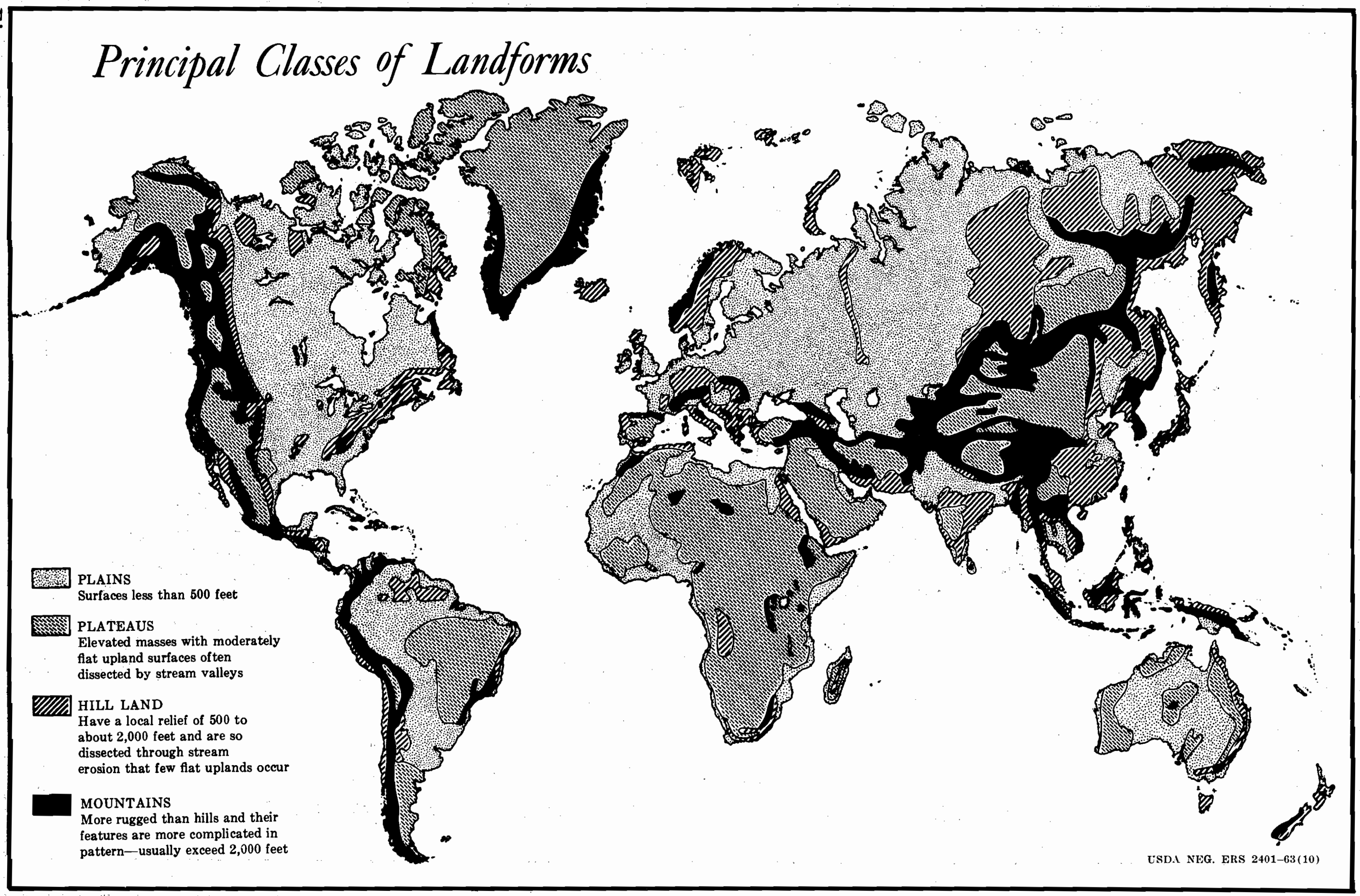
Figure 1a

Figure 2



Principal Classes of Landforms
PLAINS
Surfaces less than 500 feet
PLATEAUS
Elevated masses with moderately flat upland surfaces often dissected by stream valleys
HILL LAND
Have a local relief of 500 to about 2,000 feet and are so dissected through stream erosion that few flat uplands occur
MOUNTAINS
More rugged than hills and their features are more complicated in pattern—usually exceed 2,000 feet
USDA NEG. ERS 2401-63(10)

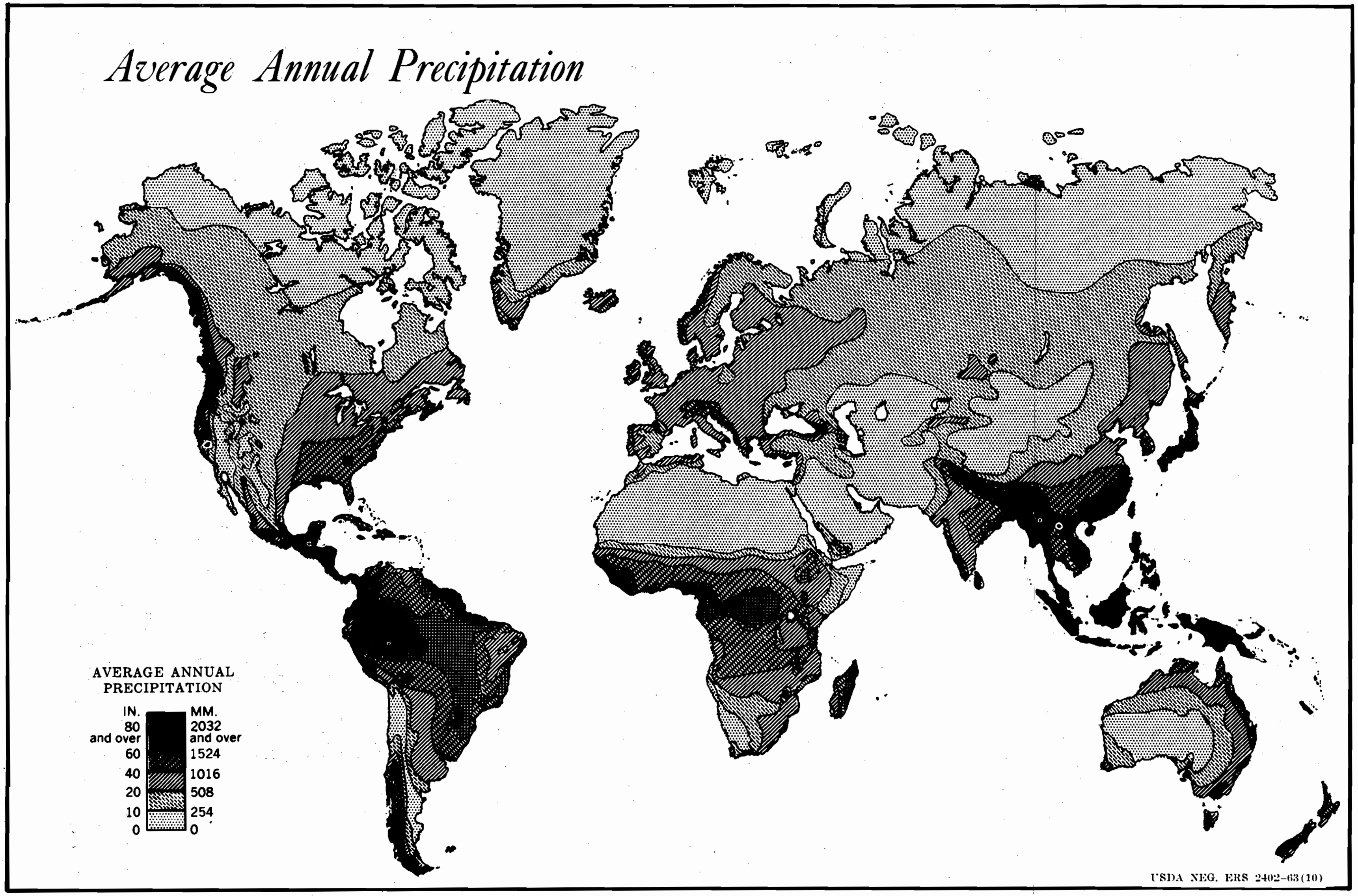

Average Annual Precipitation
AVERAGE ANNUAL PRECIPITATION
IN. MM.
80 and over 2032 and over
60 1524
40 1016
20 508
10 254
0 0
USDA NEG. ERS 2402-63(10)

Figure 3

1. Humid Tropics - dry less than 2½ months.
2. Intermediate Tropics
   a. Wet-dry tropics - dry 2½ to 5 months.
   b. Tropical savannas - dry 5 to 7½ months.
3. Dry Tropics
   a. Tropical sahelian and semidesert zones - dry 7½ to 10 months.
   b. Tropical deserts - dry 10 to 12 months.

It is clear that the duration of the dry season is paramount in crop production, since plant growth takes place for the most part in the more humid season. The growing season may be extended on deeper soils of superior rainfall storage properties, to the extent that soil management exploits this potential.

It is useful for each developing country to identify its location with respect to climate zones for two reasons; (1) the climatic characteristics and their significance to crop production is thereby recognized, and (2) other world regions in similar climatic zones may be sources of information on improved technology or superior varieties of important crop species, for local use.

Land Forms

Since climatic zones are the products of land forms and altitude, and of rainfall patterns that are determined by prevailing winds in season, as well as altitude, it is useful to examine figure 2 -- the map of general land forms, and figure 3 -- average annual precipitation.

Landforms, figure 2, are conveniently classed as:

1. Plains; with surface relief less than 170 meters.
2. Plateaus; with substantial altitudes, but with moderately flat upland surfaces dissected by stream valleys.
3. Hill Land; with local relief of 170 to 600 meters, that are so dissected through stream erosion (over geologic time) that few flat uplands occur.
4. Mountains; more rugged than hills, and their topographic features are more complicated in pattern, usually with relief greater than 600 meters, generally steep slopes and narrow valleys.

The use of these land forms for crop production is directly related to the surface slopes of the individual land areas. The plains have the greatest percentage of land with slopes flat enough to permit maximum absorption and storage of rainfall in the soil profile, and the least hazards of soil erosion losses. The plateaus are reduced in crop usefulness by the steeper slopes at the margins of stream valleys. Hill land usually has a high percentage of lands that are too steep to cultivate for crops, except as they are terraced. It is best occupied permanently by perennial forages and natural grazing lands, or by forests. Mountain areas are non-tillable except for the level lands adjoining streams in the bottoms of the relatively narrow stream valleys. Much of this land is the alluvial plain, subject to periodic flooding.

Average Annual Rainfall

The amount of total rainfall is shown in figure 3. The dominant effect of rainfall on climate may be noted by comparing figures 1 and 3. However, land forms have a distinct effect on rainfall, through the effect of altitude, and by the effect of mountains in serving as obstacles to the movement of air masses, which are laden with moisture when moving from water over land masses, and deprived of moisture when moving from land masses out to the oceans.

The world map of rainfall patterns is shown in figure 3. A convenient pattern of rainfall zones is as follows:

Over 2000 mm	annually	- rain forest
1000 to 2000 mm	"	- humid tropics
500 to 1000 mm	"	- savanna and steppe
250 to 500 mm	"	- semidesert
Below 250 mm	"	- desert

Areas with over 2000 mm of rainfall, well distributed throughout the year are well suited to production of tropical forest growth and to perennial crops such as rubber trees. However, some annual crops such as rice, taro, bananas and yams are grown successfully. The humid tropics, 1000 - 2000 mm total rainfall, have the greatest usefulness for crop production. Most of the cereal grains, the food grain legumes, the oil seed crops, the root and tuber crops, and certain fiber crops are grown successfully in this zone, particularly with adjustments to the length of the dry season. The dry season length differs with geographic location, and may be as short as two months or as long as five months.

The dry tropics - 500 to 1000 mm annual rainfall, are generally deficient in rains for crop production, but man succeeds in producing the more drought tolerant crop species by utilizing the comparatively short rainy season; and by farming only the deeper permeable soils that can store considerable rain for subsequent use by crop plant roots. Crop production must emphasize maximum rainfall retention for crop use, and it is in this regard that modern technology can contribute much to crop production. The steppe lands generally average 500 to 750 mm, and are almost wholly occupied by low growing vegetation useful for grazing livestock. Dry seasons may vary from 7.5 to 10 months.

Savanna lands may average 750 to 1250 mm of rainfall and are occupied by grasses and low growing shrubby growth. Savannas are primarily grazing lands, and only selected areas of better soils (together with alluvial soils along the streams) are successfully cropped. The dry season for savannas extends from 5 to 7 months, but the occurrence of rains is quite variable.

Semidesert areas with less than 500 mm rainfall contain extensive type grazing lands, not suited for cropping except as irrigation waters become available. The occurrence of rains is highly erratic, and there is no rainy season.

Monsoon Climates

The monsoons have a strong influence on crop production, because of the effect they have on the occurrence of the rainy season. They can be predicted to some extent, even though the basic causes of monsoon are poorly understood. The name "monsoon" is Arabic, and was originally applied to the seasonal winds of the Arabian (Persian) sea that blow about 6 months each year from the northeast, and six months from the southwest. The winds are caused by differences of annual temperature trends over land and ocean. Temperature changes are large over land, small over oceans. The monsoon blows from cooler to warmer regions; from sea toward land in summer, and from land toward the sea in winter. Atmospheric pressure is relatively high in cooler regions and lower in warm regions, permitting air movement to take place.

The monsoon type of air movement by seasons occurs throughout the tropics, and is perhaps better known in the Indian subcontinent than elsewhere. However, monsoon winds blowing from oceans toward and across land masses of Africa and South America are important factors in producing the rainy season of those tropical climates; and the reverse flow of air masses from land toward the ocean causes the dry seasons. The periodicity of rainfall in the tropics, is well established by rainfall records that are now available in virtually all developing nations.

<u>Mediterranean Climates</u> are produced by a unique combination of land forms, latitude, and monsoonal winds. Rainfall characteristically occurs in the cool months, and the summers are relatively dry. In the Mediterranean basin, air masses flowing from the Atlantic bring rains in the winter period, thus producing a type of cropping based on crops suited to the cooler moist winter season.

Natural Vegetation Zones

Natural vegetation zones, figure 4, indicate the composite effects of temperature, rainfall, land forms and altitude on vegetation. This information is useful to man, but should not be interpreted as an index of limitation, but rather as indicators of factors that must be modified by modern technology, to fully exploit crop production potential.

The natural vegetation zones are as follows:

Low latitude (tropical) forests

- Tropical rain forest
- Lighter tropical forest
- Scrub and thorn forest

Middle latitude forest

- Mediterranean scrub forest (subtropical)
- Coniferous forest (north temperate zones)
- Broadleafed and mixed (temperate zones)

Grasslands

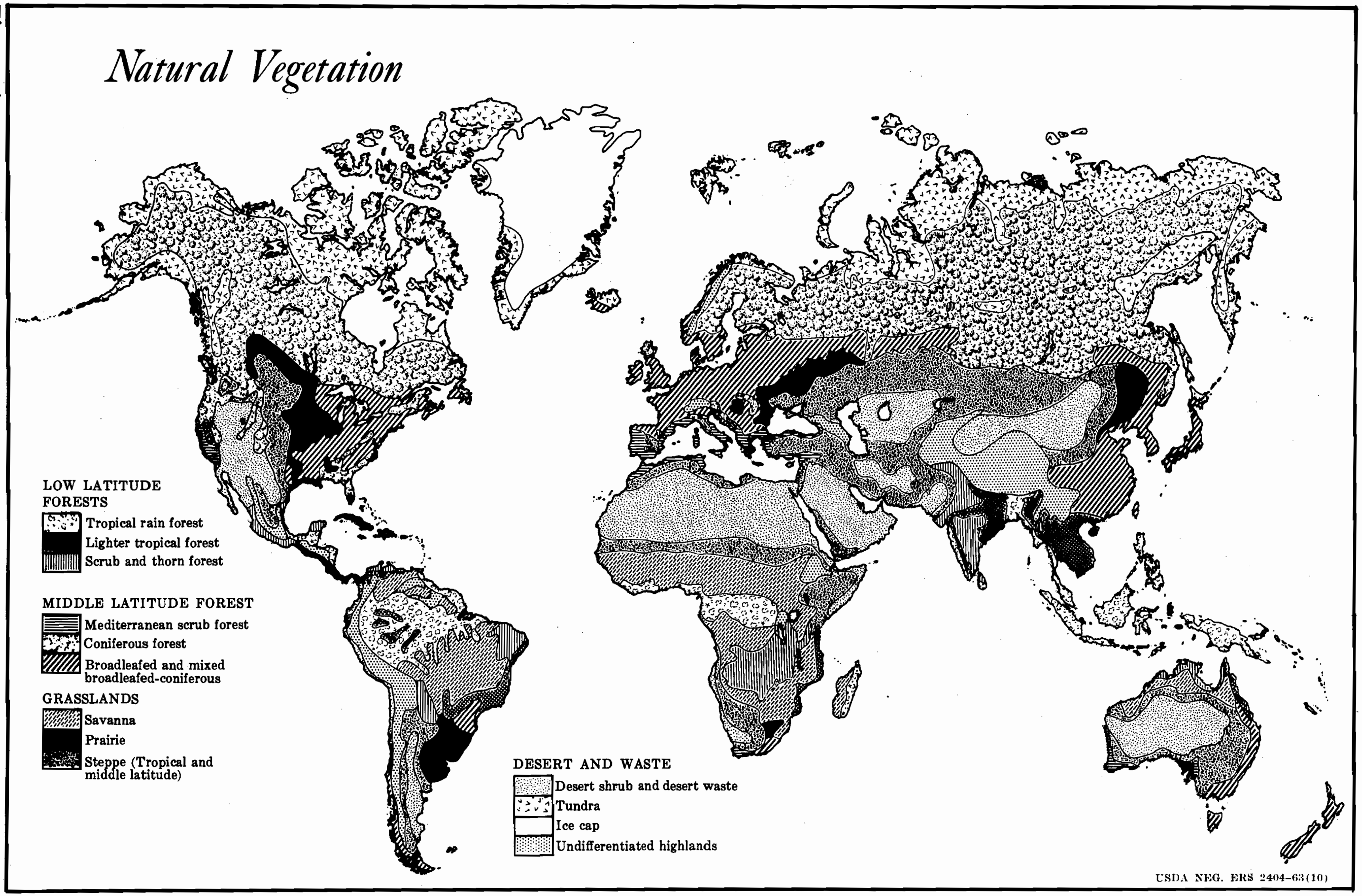
- Savanna (tropical)
- Prairie (temperate zones)
- Steppe (tropical and temperate zones)

Desert

Desert shrub and desert waste (tropics and temperate zone)

It may be noted that the only vegetation zones that occur in both tropical and temperate zones are the steppes and desert shrub. Even in these zones, the plant species of the tropical zones are quite different from those of the temperate zones. The vegetation zones of the tropics are unique, which means that the research and technology needed to utilize them to support man cannot be transferred without

Figure 4


Natural Vegetation
LOW LATITUDE FORESTS
Tropical rain forest
Lighter tropical forest
Scrub and thorn forest
MIDDLE LATITUDE FOREST
Mediterranean scrub forest
Coniferous forest
Broadleafed and mixed broadleafed-coniferous
GRASSLANDS
Savanna
Prairie
Steppe (Tropical and middle latitude)
DESERT AND WASTE
Desert shrub and desert waste
Tundra
Ice cap
Undifferentiated highlands
USDA NEG. ERS 2404-63(10)

modification from the temperate zones to the tropics. Much adaptive research will be needed, as well as original research on specific problems, to fully exploit the potential of the tropics.

Major Soil Groups

The major groups of soils of the tropics and subtropics are shown in figure 5. The map is deficient (because of its general nature) in not showing the extent and location of alluvial soils occurring along streams and in deltas. While these soils are much less extensive than upland soils, they are estimated to be providing food and other support for 25% of the world's population. They constitute a unique soil type, with some limiting characteristics of flooding and drainage, but with high crop producing potentials.

Tropical soils are unique in some respects, because of the climatic conditions under which they have developed. The effective management of tropical soils must recognize the properties of each distinctive soil group as well as the intensity and frequency of cropping and the types of crops grown. (See table 3-1)

Tropical soils are strongly influenced (1) by the character of the geologic materials from which they were derived, (2) by the soil forming processes, and (3) by the climatic conditions that have prevailed in the recent geologic era. At the very least, it is necessary to distinguish between soils produced (a) by in-place weathering of parent material, (b) by placement of sediments through stream action on flood plains and terraces, or (c) in some regions by weathering of volcanic materials. The effect of climate on soil formation has been profound, and the weathering process is different for the continuously wet climates, the tropical savannas (mixed grass and short trees and brush), the steppes (primarily grass), and for deserts. An important variant of the tropics are the highlands, particularly above 5000 ft. (1500 meters) elevation, where the climate is essentially temperate, even though placed in the tropics. The seeming endless diversity of tropical soils can be resolved into reasonable patterns, by recognizing the interrelations of climatic zones, particularly the factors of temperature and precipitation, and of major soil groups that are responsible for native vegetation provinces.

In the humid tropics with continuous high rainfall and temperature, a typical soil formation occurs, known as laterite.

Figure 5

SOIL MAP OF THE WORLD

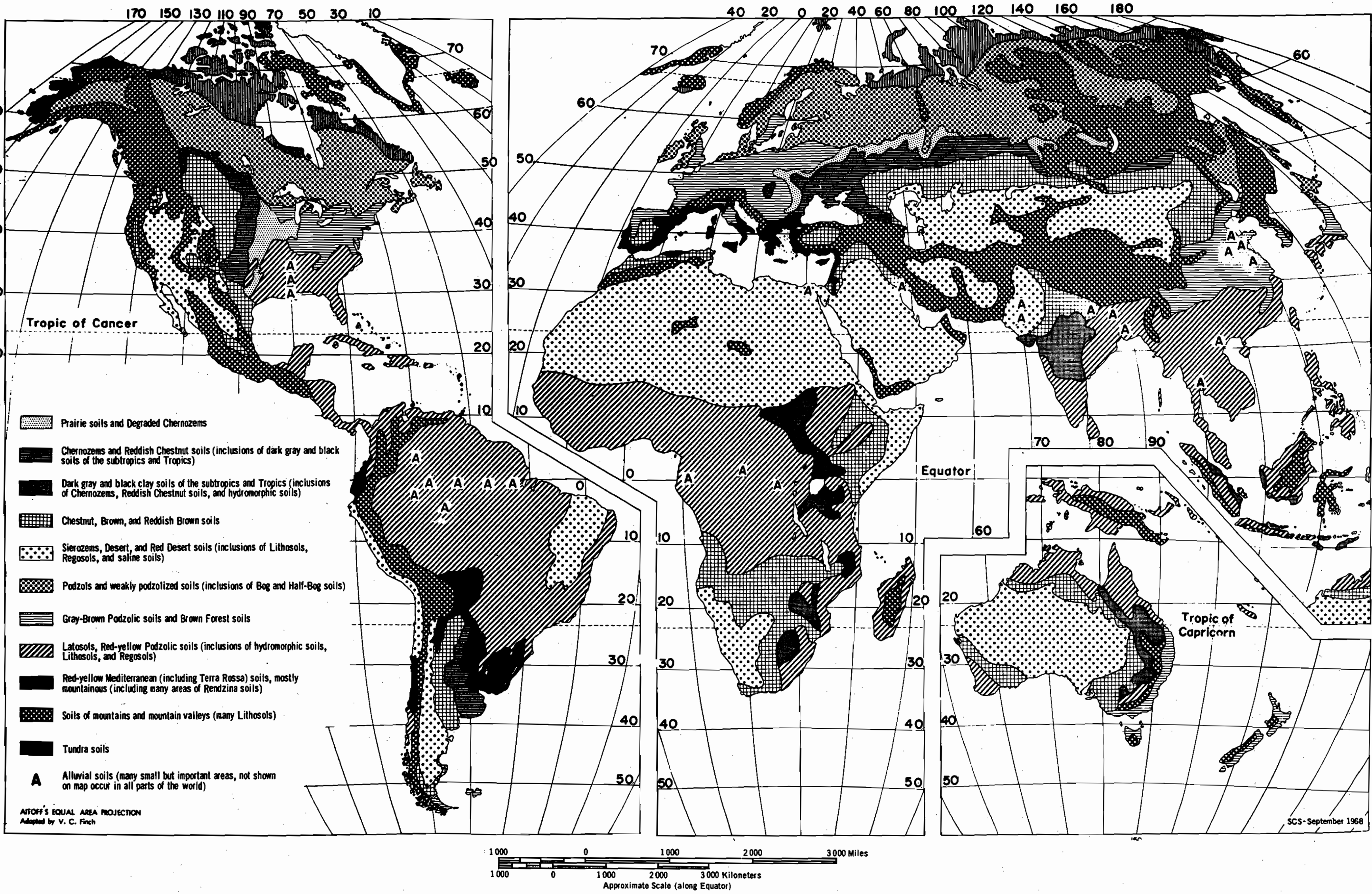


TABLE 3-1

Estimated Areas of Potentially Arable Soils
in the Tropics and Subtropics
(Both Cultivated & Non-Cultivated)*

Great Soil Groups of the Tropics & Subtropics	Total Area Hectares, Millions	Potentially Arable Soils Hectares, Millions
1. Dark Gray & Black Clay soils (inclusions of Chernozems, Reddish chestnut soils, & hydromorphic soils)	500	250
2. Sierozems, Desert, and Red Desert Soils (inclusions of Lithosols, Regosols, and saline soils)	2,798	14
3. Latosols, Red-Yellow Podzolic Soils (inclusions of hydromorphic soils, Lithosols, and Regosols)	3,214	1,382
4. Red-Yellow Mediterranean (including Terra Rosaa) soils, mostly Mountainous (including many areas of Rendzina soils)	112	17
5. Soils of Mountains and Mountain Valleys (Many Lithosols)	2,465	15
6. Alluvial Soils (innumerable areas in all parts of the world included in map units of other Great Soil Groups)	590 (Reported to support 25% of world population)	(no estimate)

(*"Potentially Arable Soils of the World and Critical Measures for their Use", pp. 109-170, by C.E. Kellogg and A.C. Orvedal, in "Advances in Agronomy" vol. 21. 1969, Pub. by Academic Press, New York.)

Laterites are leached to great depths in such climates, and they are characterized by very high contents of iron and aluminum oxides. Under certain conditions of ground-water, the laterites tend to become rock-hard upon drying, as happens when the vegetative cover is removed. This hardening of exposed laterite makes it useful as a road building material but very difficult to use for crop production. However, many forms of lateritic soil are quite productive when well managed. Under conditions of lower rainfall, lateritic soils may vary from the typical red color to gray, brown or black.

Most tropical soils are low in organic matter, since much of the lush plant growth is at or above the soil surface. Tropical soils generally respond well to animal manures and green (plant) organic matter, but organic matter is short-lived because of high temperature and moisture which accelerates complete decomposition. Insufficient attention has been given to continuing addition of green manures and of perennial forage crops as a basic requirement for continuously productive soils in tropical regions. In other respects, the successful management of tropical soils may follow principles first established in temperate zones. When essential mineral elements are deficient, they may be added as fertilizers or soil amendments. The same is true for minor (trace) elements.

When soils are impervious to rainfall, or have impeded downward percolation, the structure must be improved by mechanical treatment, or by occupation by plant types that root deeply and thereby improve permeability. When soils are poorly drained, manmade drainage systems may be installed, or they may be converted to wet-land rice paddies, as has been done in many areas of East and South Asia. For desert soils, the treatment is irrigation, to the extent that irrigation water is economically available.

The basic philosophy is that man either adjusts agricultural practices to the inherent capabilities of soils as they occur, or he identifies those limiting factors that can be altered by application of modern technology, and exploits those opportunities that are economically feasible. The farmer may not change the climate, but he undertakes to manage the soil for greater productivity, just as he manages his crops or his livestock to get greater returns for his efforts. While the knowledge of tropical soil management is still in its infancy, as compared to temperate zone soil management, there are many instances where tropical crops have been tripled in yield by a judicious combination of soil and crop management. The most important part of crop management is the choice of crops and varieties of those species that are well suited to the soils and climatic conditions where they are to be grown. When crops are adapted to their growing conditions the benefits of good agronomic practices can greatly increase their yields.

CHAPTER 3

FARMING SYSTEMS FOR THE TROPICS AND SUBTROPICS [1]

Subsequent chapters (5 through 40) of this Field Guide, deal with 36 different food crops and selected cash crops that are suited for production by farmers on small land holdings. Suggestions are made in each chapter on how to increase productivity through choices of crops suited to the environment, improved varieties, and the application of modern technology, modified practices and more useful materials. However, the methods for increasing productivity of individual crops will most likely be rewarding if the crops and practices are significant parts of farming systems that have longer range value than the current season.

Specific crops can best be utilized as component parts of a farming system, only if some comprehensive plan is being followed. The individual farmer is unlikely to act on suggested change unless it can be made clear that there will be greater protection against crop failures, that the proposals are within his capability (present and future), that he can expect greater yields as well as surpluses above family needs that can be sold for cash, and that he can expect betterment from year to year.

In Chapter 1, it was noted that the continuing population growth, averaging 2.6% yearly for the tropics and subtropics, makes it imperative that total food production be steadily improved. The objective of improving rural life requires even further increases beyond those that merely keep pace with population growth, and should include both food and cash crops. For probable success in meeting national goals, it appears necessary to involve a high percentage of the farmers on small land holdings, since they occupy most of the available agricultural lands. There are several lines of effort that may be invoked; and some planning at government levels should be useful in developing farming systems that will improve the status of farmers and also serve national development needs.

Many soils have become exhausted by overcropping. Bringing in new lands into production will not solve the problem. What is needed is to find a means for maintaining

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lands newly brought into production at a sustained level of production if food shortages are to be overcome.

Continuously productive farming systems generally have not yet been achieved for annual crops in the tropics and subtropics, but they appear within reach by more intensive studies and the full application of modern technology. The ultimate systems surely will be adjusted to the specific ecological zones such as continuously wet tropics, humid with short dry season, humid with longer dry season, and subhumid with prolonged dry seasons. However, there are some general features that should be recognized for all systems, particularly the kind of soil being farmed, which greatly modifies the influence of climate. Soil type may limit the choice of crops, even though some soil deficiencies (fertility, drainage, etc.) may be corrected.

Shifting Farming Systems

In many humid zones, shifting farming systems are characteristic, in which clearing and burning of native trees and perennial growth is followed by a few years of cropping, and then "resting" for an extended period during which native vegetation reoccupies the land. The question is how to make such lands continuously productive, since this would increase total crop land per year by several fold. Attention must be focused on the reasons why the periodic reversion of land to native vegetation restores its productivity. Accumulating evidence indicates that productivity is associated with soil organic matter, and that the decaying roots of the native vegetation are providing nutrients to the crops grown on such lands, until this organic matter is largely exhausted. The roots of native vegetation also improve the permeability of the soil to rainfall and reduce soil erosion losses, for as long as these decaying roots are present. There is a possibility that the functions of the slow restoration of soil productivity by native vegetation, can be duplicated by man's management of soils without removing them from continued farming.

The first step should be to extend the years of continued crop production, by the adoption of technology for individual crops. Such technology is outlined in the 36 chapters on the different crops. An important feature is the addition to soil organic matter by the return of crop residues to the soil, and by the use of manures and composts for producing crops. Adequate fertilization will certainly increase substantially the annual addition of crop roots to the total soil organic matter. The addition of "trace" elements needed by crops in very small amounts (manganese, iron, copper, zinc, boron and molybdenum) may be important supplements to fertilizers on some soils. Soil amendments to reduce soluble aluminum toxicity (by lime or gypsum), or to correct deficiencies in sulfur, calcium and magnesium, may be necessary.

A second step when feasible may be to grow green manure crops to restore soil organic matter. These may follow a regular crop, or replace a year of crop production. The green manure crops may be utilized for feeding livestock, but the green manure sod should be plowed under, so that decaying roots and tops will add to fertility. Small farmers are usually not in a position to grow green manure crops. More appropriate would be for them to produce an economic crop as recent research has shown that with the use of soil amendments most soils can be maintained in food production returning only crop residues to the soil.

A third step is an extension of the second step, in which perennial forages (grasses and legumes) are grown on crop land for two or more years, to make much greater and deeper root occupation, more nearly equaling the roots of native vegetation in supplying fresh organic matter. Appropriate fertilization of these forage crops will be needed for rapid root growth. The forage crops may serve as feed for livestock components (meat and milk) of farming systems, and thus provide both food and cash income. The subsequent productivity of such lands used in forage production, must be determined in comparison with land cleared of native vegetation. The labor of clearing and burning would no longer be necessary by this method; and the loss of sulfur and nitrogen, as well as certain organic constituents in the burned top growth of native vegetation, will not occur when forages replace native vegetation in long term farming systems.

Systems for Regions of Limited Rainfall

Modifications of the cropping system for humid tropics proposed in the foregoing paragraphs also may be made to adapt to less humid regions, including monsoon climates and savanna lands. The modifications will include using the crop species best adapted to these drier climates, and using forages in the cropping sequence that are well adapted to the region. The most important changes would be those that make the most effective use of limited rainfall. These should include the following:

1. Conserving rainfall:

   a. Protect against runoff losses.
   b. Store rainfall in the soil profile.
   c. Protect against wind erosion.
   d. Terrace the sloping and erosive fields.

2. More effective use of water stored in the soil:

   a. Select adapted crop species, and use improvea varieties of each crop.
   b. Grow deep rooted crop species and superior varieties of these.
   c. Correct any deficiencies in soil fertility, through fertilizers and soil amendments, to foster deeper rooting and greater yields.
   d. Use cultural practices that enhance effective use of soil water -- early preparation of the seed bed, plant early on moist soil for prompt germination, use clean viable seed of improved varieties, plant crops in rows running across slopes, control weeds, combat pests as needed, and harvest promptly to avoid crop losses and deterioration.

3. Include perennial forages (grasses and legumes) in the crop rotation:

   a. To restore organic matter to the soil through roots and stubble, and to improve soil permeability.
   b. Use forages for livestock feeds.
   c. Use forages between crop sequences for reducing inoculum and abundance of diseases, nematodes, and insects that prey on individual cultivated crops.

Crop Mixtures versus Single Cropping

A widespread practice in the tropics is to plant a mixture of several crops in the same field. The apparent reasons are to reduce possible losses, since the hazards that affect one crop are believed not likely to seriously affect the others. The crops in a mixture are usually planted in rows. Often, any vacant areas from an initial planting, are filled by later spot planting of other crops.

Some experimental evidence has been reported to support the benefits of such mixtures in obtaining optimum yields from a given area in a given season. Extensive investigations in this area are being supported at the international centers of tropical agriculture in Colombia (CIAT) and Nigeria (IITA) with maize, beans, cowpeas, groundnuts as a base and at IRRI in the Philippines with rice, sorghum, soybeans and maize as the major crop varieties for intercropping.

Since each nation is faced with the necessity of increasing total food (and cash) crop production by at least 2.6% every year to keep pace with population growth, and each farmer must improve his own productivity to provide for his family and enhance his living status, it will be necessary to make the most efficient use of land. Some changes appear inevitable if increased productivity is to be achieved. The following factors need consideration:

a. Which method permits the most effective application of the technology to the individual crop, such as;

(1) Improved varieties.
(2) Effective seed bed preparation to suit each crop.
(3) Time of planting adjusted to season and rainfall.
(4) Kind and amount of fertilizer, and fertilizer placement for specific crops.
(5) Method of planting suited to the species.
(6) Planting in rows, across slopes, to reduce rainfall runoff and erosion losses.
(7) Weed control.
(8) Use of rotations of individual crops to prevent the carry-over of specific diseases, root nematodes, and insects. Each crop type has its own pests.
(9) Varying the areas planted to key crops (food or cash) to meet anticipated needs or markets for the current season.
(10) More knowledge and timely observations on growth and performance of each crop.
(11) Convenience in harvesting each crop when ripe, without damage to others.

b. What are the end results in terms of labor and material costs of production, in yield of crops, and in their quality?

It appears that crop mixtures have more disadvantages than advantages in a system of large-scale farming where single crops are essential in reaping the potential benefits of modern machinery and technology applied to crop production. Intercropping is more adapted to the small farmer where farming is more intensive. Increased research is necessary to satisfy his specific needs. It is suggested that if a rotation of the same crops (for example, three crop species) were raised, each crop would appear on a specific field once in three years, and specific pests would be decimated when the host is not present. A similar situation exists for root-nematodes, soil infesting fungi and insects, and even to certain flying insects. Also, field sanitation is feasible, to remove, or plow under, all crop residues after harvest as a means of decimating pests that would otherwise survive and attack the next crop. Such sanitation is more likely to be carried out if only one crop is grown on each field.

It is suggested that some time-honored practices be questioned; such as shifting cultivation patterns and cropping practices that do not deal effectively with the specific limiting factors of the environment (rainfall uncertainty, deficient soil fertility, etc.). They should be re-examined, and compared with other practices based on technology borrowed from other regions, or developed from new research. Such efforts are needed to meet the imperative demands for increased and more efficient production of food and cash crops to serve the nation, and to improve the living status of farmers on small land holdings. An excellent place to begin, is on improved production of individual crops. Suggestions for this are offered in Chapters 5 through 40 of this Field Guide.

The subsequent chapters on individual crops should not be construed as recommending piecemeal innovations in farming practices. However, each component in a farming system should make a satisfactory economic contribution, or it is not likely to survive. Increases in productivity should be quite substantial to produce a sufficient incentive to adoption by the farmer. The individual farmer must see immediate benefits, and also become convinced that continued progress is feasible.

Two factors must be recognized; <u>One</u>, that substantial yield increases of any crop require the simultaneous application of all or much of the available technology (a new variety, without the rest may do little, or fertilizer used without other changes is not worthwhile). Two, a system of farming that utilizes many productive components has a multiplying effect on long-range farm profitability.

The system of farming developed for each region must be attuned to the conditions prevailing in that specific region; systems may need to recognize bottlenecks on seasonal labor, patterns of land use and tenure, available supplies and equipment for production, credit, extension and education programs, governmental policies and price supports, marketing practices and markets, and other matters. This Field Guide does not cover those important matters; but it does undertake to provide information that is widely applicable to specific crop production.

CHAPTER 4

GENERAL PRINCIPLES OF IMPROVED CROP [1/] PRODUCTION IN THE TROPICS AND SUBTROPICS

The Keys to Increased Yields and Net Returns Per Hectare

With the important successes on production of rice and wheat on a worldwide basis and maize in East Africa that have been achieved since 1968, it is useful to identify the basic principles that were invoked, and to utilize these as guidelines for extending these accomplishments to other crops and new regions not previously affected. After 10 to 20 years of research with rice in the Philippines (by the International Rice Research Institute, IRRI), with wheat in Mexico (International Center for Wheat and Maize Research, CIMMYT), and with maize in Kenya and northern Tanzania (Major Cereals Program by USAID-U.S. Department of Agriculture), each of these organizations has succeeded in developing highly productive plant materials and combinations of cultural practices for greatly higher yields. These major achievements were not only due to the great success achieved in breeding more productive types of each crop, but also to determining how to employ all of the component practices in crop culture to exploit fully the potential crop productivity. All of the individual components must be put to work simultaneously to achieve greatly increased crop yields, at relatively low additional costs in labor and materials. The effect has been to greatly increase the net returns to the grower.

The breeding of improved crop types was a key component of these successes. These improved types of rice and wheat were short, stiff-stalked and resistant to lodging, adapted to the tropics and subtropics (not sensitive to length of day), resistant to important insect pests and diseases, and with great potential for responding to good soil fertility. The package of cultural practices included effective use of irrigation water for rice and wheat, timely planting of superior hybrids of maize especially bred for local conditions to make optimum use of the "rainy season", sufficient fertilizer to permit greatly increased yields, seeding rates to produce high enough plant populations to fully utilize the environmental conditions, effective weed control, and prompt treatments to control important insect pests and diseases. Finally, the crop was harvested promptly to avoid deterioration in the field, and processed by appropriate drying and cleaning before being put in temporary farm storage.

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The significant feature was the combination of outstanding newly developed crop types with all of the necessary cultural practices to permit full expression of the yield potential. The result has been to increase yields to heights previously considered unattainable, but which proved highly practical when employed by the cultivators of all sizes, large and small, under the guidance of leaders who fully understood the process. Crop yields have been increased 2- to 4-fold under reasonably effective management; and the values of the increased yields have greatly exceeded the additional costs of seed, labor and fertilizer.

These phenomenal results obtained through a multidisciplinary approach with these three major crops point the way to increased efficiency in other areas and with other crops. Substantial benefits may be achieved at once by applying those technologies now available, with the prospect of still greater advances when the adaptive research on crop culture, and the plant breeding to develop superior crop types, have been completed. The following aspects of crop production have been sufficiently proven to warrant wide application.

1. Choice of Suitable Crops

The crops currently being grown should be compared with others that may be considered, to meet local food needs, to exploit potential markets, to provide adaptation to local climate and soil conditions, and to fit feasible farming systems. Choices may be made between crops of the same type, or between types. For example, of the cereal grains, rice is without a competitor on soils subject to flooding. For upland soils, rice is suited only to regions of abundant rainfall, but maize may be more productive on fertilized fields in regions where occasional moisture shortages occur, particularly if local soils permit deep rooting. Sorghum should replace maize in regions of greater moisture deficiency or stress; and millet (bulrush type) is more productive than sorghum where rainfall and soil moisture supplies are still more uncertain.

A choice of food grain legume may depend on climate and soil; thus, cowpeas are better adapted to regions of abundant rainfall; field beans are adapted to regions of moderate rainfall; chickpeas and lentils are best grown in subtropical regions with moderate rainfall in the cool season; and other species prefer other characteristic environments. As examples of starchy crop adaptations, bananas and plantains require fairly constant and ample rainfall and soil moisture, in contrast to the tolerance shown by cassava for periodic moisture shortages. Also, among the oil seed crops, sunflowers and safflower are the most drought tolerant types; groundnuts require a growing season of 4 to 5 months when moisture supply is moderate to good, but will grow well in regions with prolonged dry periods; sesame may be grown in a wide range of rainfall zones from heavy to moderate, provided the ripening period is relatively dry.

The important factors are those that are adaptive to the climatic and soil conditions of the region, so that higher yields are possible under improved cultural practices. A very crucial aspect of environmental adaptation is the response of individual varieties. There is no substitution for actual field trials (of varieties or hybrids) under farming conditions representative of the region. A collection of improved varieties of each crop, including outstanding varieties tested in field experiments of several regions, should be evaluated to select some promising candidates, so that only the best will be grown in direct comparison with improved varieties of other crop species. Tradition or custom is not a reliable criterion for choice of a suitable crop; there is no substitute for actual field testing in which modern technology is applied to the culture of each crop. Even though the crop species may prove to be reasonably well adapted, the potential productivity of improved varieties or hybrids may be found to be much greater than that of locally common strains or variety of that crop.

The individual grower is not in a position to make dependable studies on which crops are best suited to specific regions. This type of investigation should be the responsibility of research stations in each major farming region. When these studies have narrowed the choices to a few alternate crops, the grower should then be enlisted to make final comparisons. The growers should have the guidance of agriculturists who will advise on the appropriate cultural practices, so that the final results will truly represent the productive capacity of the several crop types.

2. Land Clearing, Preparation, and Fertilization

Land clearing and preparation vary greatly with climatic regions, as noted in preceding chapters. The prevailing practices generally reflect accommodations of the grower to environmental conditions that he has learned to accept as the price for survival. They do not necessarily indicate feasible limits of productivity. Since much of the technology developed over the past two centuries in the temperate zones must be greatly modified when applied to tropical regions, there is great need for continued studies on how best to proceed in land preparation on each of the major soil groups of the tropics and subtropics. A more complete understanding on how to make all tropical soils continuously productive requires further research.

The first step is removal of all woody growth, or at least the killing of such vegetation. In humid regions, where the land is "fallowed" for a period of years after cropping, the forest growth is generally cut and burned; and the subsequent crop is planted around the remaining stumps and logs. The burned vegetation leaves a residue of ash; the most important components being phosphorous, potassium, calcium, magnesium, and the trace elements to a lesser degree - copper, zinc, iron, manganese, boron and molybdenum. Unfortunately, the burning vaporizes all of the sulfur and nitrogen in the top growth, both of which are essential to plant growth. The roots of the forest growth are decomposed largely during the first crop year, and contribute mineral nutrients to the extent that the crop plant roots penetrate the soil profile. The fertility provided by the decomposing roots is largely exhausted in two to four years, which explains why crop yields become successively reduced and the fields are allowed to revert to native vegetation after a short period of cropping for a period of natural regeneration.

The removal of woody growth also is necessary on savannah lands, but the amount of wood is greatly reduced. Also, the release of plant nutrients from decomposing roots is retarded by dry periods, so that the soil fertility status does not decline as rapidly as in more humid regions.

The dark grey and black soils of the tropics and subtropics are somewhat higher in native fertility than the lighter colored soils, but there are marked variations in such soils. Also, the alluvial soils of river systems usually have higher fertility and, whenever these are more permeable, they permit deep root occupation and utilization of soil nutrients from all profile layers.

In all soils, the use of manures and/or fertilizers is a prime requirement for higher yields of crops. As in North America and Western Europe, the major nutrient requirements are nitrogen, phosphate and potash. The nitrogen compounds in commercial fertilizers move readily into soils, but the phosphates and potash must be positioned in the soil where they will be readily accessible to crop roots, to be effective. The amounts of fertilizer, and the ratios between nitrogen, phosphate and fertilizer, cannot be standardized, since all fertilizers are added to make up the differences between that derived from the soil and the total amount required for optimum crop yields. Actual field trials on fertilization of specific crops are the most reliable guide to fertilizer requirements, and these should be planned and conducted by trained specialists. An aid in determining fertilizer needs is laboratory testing of representative samples of field soil to estimate the soils capacity to supply phosphate and potash. The results of such laboratory tests must be calibrated in terms of field tests, and interpreted by the specialist in terms of the kinds and amounts of fertilizer that may be applied with benefits.

Many tropical soils appear to be deficient in the so-called "trace elements" that are required by plants for normal growth, but the amounts needed are very small. The alluvial soils of the lowlands and terraces of stream valleys are less likely to be deficient in these trace elements than upland soils. Phosphate fertilizers and animal manures and composts usually contain some calcium, magnesium and sulfur; additional crop requirements may have to be determined by field fertilizer trials. However, the "trace elements" which are essential in small amounts for normal crop production (zinc, iron, boron, copper, manganese and molybdenum) are not likely to be found in commercial fertilizers unless specifically added. Animal manures usually contain appreciable quantities of these trace elements.

There have been field trials in a few regions of the tropics in which the addition of a few kilos per hectare of a mixture of trace elements actually doubled crop yields above the increases from fertilizers alone. Since much more research is needed to determine which one or ones of the trace elements are deficient in particular tropical soils, one of two methods may be used to eliminate these possible limits to crop growth; (1) apply a mixture of <u>all</u> trace elements along with fertilizer, or (2) when available make maximum use of animal manures or composts. The manures may be less effective than a mixture of trace minerals, but their use is more easily achieved by small cultivators. If animal manures are used as fuel, the ashes should be carefully saved and spread uniformly on crop land.

3. <u>Conservation, and Soil and Water Management</u>

Tropical and subtropical soils generally are subject to strong soil erosion when cropped, although the erosiveness varies with the different kinds of soil. Both the immediate and long-range effects of erosion reduce crop productivity. In general, the greater the slopes of the land, the greater is the erosion hazard. Whenever rainfall occurs faster than it permeates the soil, it flows down slope and carries with it greater or lesser amounts of the more fertile top soil and exposes the less fertile subsoil. Continued water erosion also produces gullies and gradually destroys useful crop land. Such erosion is often more serious on savannah lands and on short-grass steppes, than in more humid regions, because rains come in heavy showers much faster than the soil will absorb the water. Water erosion in the dry regions, on rangelands, is a serious problem. In general, the tillage and lack of complete ground cover, that is typical of annual food and cash crops, predisposes most farm lands to serious erosion damage.

Runoff of rain water has immediate adverse effects on crops grown in regions where "dry-periods" of one month or longer occur. Except where water-logging occurs because of inadequate internal drainage, the objective in soil and water management should be to retain and store the maximum amount of rainfall in the soil profile for use by crop roots. Vast areas of the tropics and subtropics, on all continents, regularly experience "dry" periods with little or no rainfall, ranging from one to six or more months. The degree to which water can be retained and stored in the soil during rainy periods will extend the crop growing potential of these regions. Soil management practices should be strongly oriented toward conservation of as much rainfall as feasible for crop use in regions having dry periods. The achievement of this objective will depend to a great extent on the inherent soil properties and soil depth, and on soil mapping to establish crop producing capabilities of the major soil groups, to provide basic information of importance to agricultural development programs. The management practices should be designed to enhance water conservation to compensate for inherent limiting soil characteristics, so far as feasible.

The least difficult of the management practices are also those that are least adequate in controlling soil erosion and water losses. As the losses become more critical to permanent agriculture, more elaborate conservation measures are required. The following practices are feasible on a majority of tropical soils that are subject to soil and water erosion.

a. Crop residues should be left on the land to act as a surface mulch. All animal manures and composts should be spread on the land to contribute to soil fertility and increase the soil's permeability to rainfall.
b. Use alternate strip cropping across land slopes of different crops, rather than larger areas

of single crops, to reduce rates of runoff. Closely planted crops should alternate with crops using wider spacings.

c. Always till land so as to provide a rough surface to retard water flow and enhance penetration of rainfall. So far as feasible, tillage should precede expected heavier rains to reduce runoff.

d. Choose deeper rooting crop types and correct the soil fertility deficiencies to enhance crop growth, so as to maximize crop yields per unit of water consumed by the crop.

e. Fully explore the opportunity for growth of forage and fodder crops to support livestock enterprises, in rotation with tilled crops. The solid stands of most feed crops have a beneficial effect on soil structure, that enhances yields of the succeeding tilled crops. Crop rotations generally are superior to continuous cropping to a single crop type.

f. Where soil erosion and gullying are not controlled by simpler practices, undertake a program of soil terracing, as feasible, accomplished best by field machinery and tractors, to permanently change field contours for more effective cropping.

4. Improved Varieties and Types of Crops

Great advances have been made in the last two decades, in assembling rich collections of types and varieties of each of the more important crops. These types and varieties cover a wide range in plant and seed characteristics, length of growth period, adaptation to climatic differences, tolerance or resistance to insect pests and diseases, crop quality, and ease of harvest. From such collections, greatly improved strains have been selected as being more productive for specific regions than locally grown types.

The next step in crop improvement is to undertake breeding programs, to combine into a single type, the desired characteristics from two or several types. The "miracle" rice varieties, the outstanding "Mexican" type wheats, and the greatly superior maize hybrids for East Africa were the result of such breeding programs that combined tremendous production potential with other superior traits. Parallel research on cultural practices, to permit full expression of crop yield potential, resulted in a "package" of improved plant materials and cultural practices that increased yields 2- to 4-fold greater than had been achieved by indigenous agriculture.

It is now clear that such methods are applicable to most cultivated crops, dependent only on the coordinated undertaking and completing the necessary research and field testing. The initial step of collecting and field testing a broadly based collection of types and varieties of each specific crop is within reach of every developing nation. By taking full advantage of the various international research and training networks that are being developed for the major food crops parallel research on cultural practices best suited to the local environment, so as to capitalize on the best adapted types or varieties, can be carried out in each nation with moderate costs, with prompt benefits to the growers. A strong breeding program to carry the process still further requires a research program of several years duration, carried out by competent plant breeders. If a developing country lacks this capability for all important crops, an alternative choice is to arrange with a research institute in some other country with similar soils and climate to acquire seed of new crop selection and to test these products of the breeding programs of such institutes. It should no longer be necessary for growers to struggle with low production potential of any major crop. Every developing nation should fully exploit the modern technology that has produced superior strains and/or hybrids of each crop species.

5. Seed Production and Distribution

The availability of clean viable seed has a high priority in all agricultural regions. However, a system for production and distribution of seed has the greatest significance in connection with improved crop strains and varieties or hybrids. The individual grower cannot depend entirely on external sources of seed, and he should be advised as to which crop types will breed true from plant generation to plant generation, that will permit him to produce and store his own seed. For crops that show great variability in successive generations (which is true of all cross-pollinated species), the maintenance of identity and purity of type requires field isolation from all other types, and appropriate controls to insure crossing to produce the true type, or to limit out-crossing to that occurring within the selected type. For crops that do not breed true without man's intervention, seed production is a specialized enterprise that requires government regulation and inspection, to produce seed that is guaranteed as to identity and quality.

For crop species that breed true from generation to generation (such as wheat, beans, sesame, etc.), the grower may produce and store his own seed successfully making sure he avoids any mixing in planting, harvesting and cleaning. This process includes elimination of off types in the field, prompt harvest of seed at maturity, careful drying (with protection from rain), effective cleaning to remove foreign matter, and storing so as to remain relatively dry (below 10% moisture). Where possible the grower is urged to replenish his seed stocks periodically to be sure he is planting the best seed possible.

6. Planting Practices

These practices include the best season for planting, the quantity of seed to provide full occupation of the land for higher yields, the method and depth of planting, and spacing to facilitate pest control and harvest.

In general, the season of planting should be selected to coincide with the beginning of a rainy season (which is highly important in regions of limited rainfall), or to have the crop mature in a period after rains cease. In the case of irrigated regions, or regions of abundant rainfall, particularly for rice, date of planting may be adjusted to permit multiple cropping in the course of a year. Prompt planting at the beginning of a rainy season appears to be effective to take advantage of higher natural soil fertility levels at that time, and to escape the insect pests and diseases that gradually build up after rains begin and damage later seedings more severely.

The quantity of seed planted should be such as to produce a total population sufficient to fully utilize soil fertility, but not so dense a planting that soil moisture supply will be exhausted before the crop matures. Obviously, the plant population that produces the greatest yield at maturity of the crop must be adjusted to the growth characteristics of the crop, the average expectancy of rainfall, and the fertility and water supplying power of the soil.

Depth of planting must also be adjusted to the conditions of the seed bed and expected weather. Seeds require moist soil for germination, and thus must be placed at least 1 to 2 cm below the surface. Heavy textured soils that tend to crust as a result of rains constitute a problem. Seed must be planted shallow enough to break through any crusts that develop, but deep enough to remain moist as required for germination. Large seeds tolerate deeper planting, and have greater germination power to force the seedling shoots through soil crusts. A method successfully used in some regions to combat soil crusts is to plant seed in hills in excess numbers, and to thin to the desired stand after full emergence of seedlings.

Hill planting is quite compatible with rows spaced to facilitate weed control, and for any treatment needed for control of insect pests and diseases. Where hill spacings are less than the distance between rows, the rows should run across slopes, on contour lines, to retard soil erosion damage and runoff losses.

7. Weed Control

Except for freshly cleared land, particularly in humid regions, weeds constitute a major threat to high crop yields. Fields that are continuously cropped to annual crops, usually experience a rapid increase in abundance of weeds from crop to crop. Weed competition then becomes a serious threat. It is essential that all planting seed be weed-free, but this is often ignored.

Weeds are best attacked while very young, since they are more easily killed at that stage, and later killing does not prevent substantial reductions in crop yield by root competition between weeds and crop seedlings. The crop never fully recovers from early, heavy infestations with weeds, even where the weeds are completely eradicated in a few weeks.

The traditional methods of weed control are pulling and hoeing or tillage. With a plentiful labor supply, these methods can be effective, but only if weeds are removed while still quite small. Later removal by these means, inevitably damages the root systems of crop plants. Repair of such root damage becomes progressively less probable as soil moisture supply dwindles, and as fertility has been sapped by weeds.

Many serious weeds can be eliminated by application of chemical herbicides that kill the weeds without harm to the crop plants. These herbicides must be selected to attack the specific weeds that are prevalent; and they must be used precisely as prescribed by the manufacturer of the herbicide. As crop culture becomes more commercially oriented, the use of herbicides becomes quite practical. A great advantage of an appropriate herbicide is that rapid treatment of extensive areas is possible, whereas hand control by pulling or hoeing would take much time and allows weeds to seriously curtail ultimate crop yields.

8. Control of Insect Pests and Diseases of Crop Plants

While these pests vary widely with the type of crop and the agricultural region, there are certain principles that are generally applicable to effective control by the individual growers.

Where strains or varieties have been bred for resistance to important insect pests and diseases these give the grower a great advantage. Unfortunately, such breeding programs have still not been undertaken for all crops, and some types of resistance cover only a portion of the pests found in specific localities. To the extent that resistant crop types are available, they should be used.

A second principle is based on the rapid multiplication of both insect pests and diseases as the growing season progresses. Early planting to establish crop plants before the insects or the disease inoculum increases in abundance, and perhaps to permit crop ripening before excessive damage occurs, is generally effective. A related principle is to attack these serious pests as soon as they appear to prevent a build-up in abundance. The small-holder has a serious disadvantage in that his control measures can only be fully rewarding if all neighboring fields are treated effectively. Insect pests are highly mobile; and the inoculum of diseases is carried from field to field by winds and by some birds.

For diseases that are seed-borne, it is necessary to either plant disease-free seed or to treat all seed with fungicide chemicals that destroy the disease organism. Home-grown seed is almost inevitably infected with some diseases, and chemical treatments should be useful if faithfully used as prescribed by the manufacturer.

Use of pesticides

The use of appropriate insecticides and fungicides to combat insect pests and diseases has been more highly developed for a few cash crops of high value, such as cotton; and both the appropriate pesticides and directions for using these are generally available in important cotton-growing regions. For most other crops, the methods and materials for combating pests require more attention by growers and their advisors. A first requirement is to accurately identify the pest.

Control measures for serious insect pests must be adjusted to the life cycle of the specific insect, its feeding habits and reproduction. The time and method of attack should be planned to have direct effect on the specific insect. Indiscriminate and continuing insecticide treatments may be more harmful than beneficial, as well as being unnecessarily expensive. If an insect is causing serious damage in one field, it is probably abundant in other fields of the region, and a community program of treatment should be organized by local advisors. All other methods of controlling specific insects should be invoked, including use of resistant varieties, early planting to evade heavy infestations, crop rotation to reduce the abundance of vulnerable crops, and any suitable methods for killing the insect in periods between crops. Insecticides should be used only to supplement other control measures as a last resort. Such planned control obviously requires a rather full knowledge of the insect and its habits.

Preventing diseases

Similar attitudes should prevail with respect to plant diseases. A prime requirement is to identify the causal agent for the disease. In addition to determining if the agent is a fungus, bacterium, virus, or nematode, it is essential to determine which organism or type of organism is involved. Where the causal agent has already been identified, as with a well-known disease, the control measures follow somewhat the same pattern as for insect control: (a) use resistant varieties, if available; (b) plant only disease-free seed, or seed that has been treated to kill contaminants; (c) evade or delay infection by early planting before the inoculum increases in abundance; (d) if certain insects are known vectors for transmission of disease (viruses), direct the necessary efforts to control of these insects; (e) growing other crops not affected by a serious disease, to reduce rate of spread from field to field; and (f) any appropriate measures for reducing inoculum in periods between crops which includes controlling weeds as they appear in the fields and the borders.

9. Harvesting and Drying

Crops should be harvested as soon as grain maturation is complete, and sun-drying in the field has reduced moisture content to the extent possible in the local climate. The preferred moisture content of the crop in the field should be less than 20%, and below 15% will simplify further drying in storage. Seed and grain should be reduced in moisture content in the field when drying conditions prevail, since this is the simplest and cheapest method of reducing moisture to the 10% required for safe storage. However, a compromise may be necessary to protect the crop from birds, rodents and insect depredations. Such early harvest must be followed by measures to complete drying on open floors or ventilated storage. The grain will dry more rapidly and safely if all foreign matter is screened out when the crop is brought in from the field.

Grain or seed infesting insects constitute a serious menace to all stored grain and seed in the tropics. The hazard is greatest in humid climates, but major losses occur also in dry climates. Where experience indicates the probability of heavy insect damage, guidance should be sought on practical treatments that will eliminate insects at the time grain or seed is placed in storage. Preventive treatments are more effective and far less costly than trying to control infestations after they occur.

10. <u>Primary Cleaning and Processing of Crops</u>

The initial handling of harvested crops as they come from the field has a direct relation to net returns to the grower. The crop should be dried as rapidly as feasible to moisture contents that will assure safe storage, processed for removal of all foreign matter, given screening or sorting to eliminate all non-salable portions (and those that will not store safely), and given preliminary treatments to suppress storage insect infestations.

While all of these practices are feasible and necessary for crops entering market channels, the need for such processing is probably nearly as great for growers who are using short-term farm storage prior to marketing, and for all stocks held on the farm for family food supplies. From fragmentary reports as to severity of on-farm storage losses, effective methods of curtailing these losses would contribute very greatly to net returns achieved by growers in virtually all developing nations. It would be sensible to protect the crop for full utilization after it has been produced and harvested. Failure to do so may largely dissipate the benefits resulting from more efficient field production. The technology for feasible, inexpensive on-farm processing and storage of grain and seed should be given increasing attention.

CHAPTER 5

RICE (*Oryza sativa*) [1/]

Rice is a leading cereal crop in many countries and is grown on all continents. It is the principal staple food in the diet of more than half of the world's population. About 90% of the world's rice crop is grown in Asia. Outside of Asia and adjacent islands, important rice-producing countries include Brazil, Colombia, and Peru in South America, Egypt and Malagasy Republic in Africa, the United States and Mexico in North America, Italy and Spain in Europe, and Australia. Although the United States produces less than 2% of the annual rice crop, it is the leading exporter of rice since over half of the production is exported. Rice is an ancient food plant of the Far East and dates back at least to 3,000 B.C.

Rice often is considered a tropical crop but it is grown in both the temperate and tropical zones in Africa, Asia, North America, Oceania, South America, and in the southern part of Europe. Rice yields generally are much higher in temperate than in tropical zones because of differences both in climate and in cultural practices including varieties grown. However, new high-yielding varieties and improved cultural practices developed by International and In-Country Research Stations have shown that high yields also are possible in tropical zones.

The rice crop is unique in the ability of its seed to germinate in water and the plants to grow on flooded soils. However, rice seeds usually will not germinate if covered by both soil and water. Rice may be grown as irrigated or lowland (wetland) rice, or as upland (rainfed) rice which is not irrigated. The two general types of production require different cultural methods. In developed countries where grain yields are rather high, most rice is grown under controlled irrigation. Several systems of controlled or uncontrolled irrigation are used in various countries to supply the needed water for proper growth of the rice plant.

Considerable rice is grown on upland soils but this type of culture usually is limited to areas of relatively abundant rainfall during the growing season. In some cases the rain water is impounded and in other cases it is not. Much of the rice grown in Central and South America and in many countries in Asia is produced under upland conditions. Fairly satisfactory yields may be produced in seasons of uniformly high rainfall but dry seasons may bring about very low yields. In the Philippines and elsewhere in Southeast Asia, much of the rice is grown on terraces in mountain regions. Sometimes the entire

[1/] Edited by T.H. Johnston, Research Agronomist and Technical Advisor, Rice Breeding, Southern Region, Agricultural Research Service, U.S. Department of Agriculture, in cooperation with University of Arkansas Rice Branch Experiment Station, Stuttgart, Arkansas 72160 mountainside has been converted into a series of rice paddies. Spillways permit the impounded water to flow down from one terrace to another.

Floating rice is grown in some areas of southeastern Asia where streams overflow during the growing season. Specially adapted varieties are sown before the flood season. The water rises slowly and the plants elongate rapidly as the depth of the water increases. The rice culms are weak but are supported by the water. When the flood water recedes, the plants lodge but enough upright growth is made to hold the panicles off the ground so grain can be produced. Such rice must be harvested by hand. In recent years rice breeders in Thailand, and perhaps elsewhere, have had some success in developing floating varieties that show reduced straw growth and more resistance to lodging. However, the plants have retained the ability to elongate rapidly when the need arises.

Environmental Requirements

Temperature and Water

Rice needs relatively high temperatures during the entire growing season, and hence is restricted to tropical climates or to warm seasons of subtropical and temperate zones. The water requirement for rice is rather high and lowland rice may be flooded most of the growing season which may extend over a period of 3 to 5 months. The amount of irrigation water required is least where the subsoils are relatively impermeable and the seasonal rainfall is high. Water of good quality is needed for satisfactory rice production.

Considerable variation exists in methods used to provide water for irrigation. The water source may range from natural seasonal flooding of low-lying areas along streams to elaborate systems of dams, impoundments, and canals to provide complete water control. Water may be pumped from wells or may be obtained from streams by means of relift pumps and use of open ditches trend is toward development of well constructed and efficient irrigation facilities that make maximum use of water for year-round crop production where temperatures are suitable. The more primitive systems that depend on natural flooding may produce relatively low yields of rice because of the uncertainty of water supply, and the difficulty of timely execution of cultural practices including weed control and fertilization.

Effective irrigation implies not only an adequately controlled supply of good quality water, but also efficient drainage of excess water whenever this is required. In cases where rice is direct-seeded rather than transplanted, good drainage is needed to allow the land to dry out enough for preparation of a satisfactory seedbed. Sometimes it is necessary to drain a rice field to allow the soil surface to dry and permit aeration of the rice root system in early midseason to prevent damage from straighthead disease. Earlier drainage may be needed to lessen chances for damage from adverse soil conditions or from insects such as the rice water weevil. Flooded rice fields usually are drained 1 or 2 weeks prior to maturity of the rice. This is especially necessary when rice is harvested mechanically or when storms cause the rice plants to lodge or fall over severely. If it is not possible to drain fields adequately at this stage, then it is very important that the rice varieties being grown possess postharvest dormancy; otherwise the grains on culms which have fallen into the water will germinate while still on the panicle.

Soils

Lowland (wetland) rice is grown mostly on rather heavy clay soils or other soils underlain with a hardpan or impervious subsoil. The seepage loss of water through such soils is small and these soils may not be as suitable for other crops which require deeper root systems to produce satisfactory yields.

Upland or rainfed rice is grown on soils of many types, in regions of high to moderate rainfall where the soil profile may be wet most of the time or only occasionally. Upland rice therefore is generally far less productive than irrigated rice, especially in low rainfall years.

Soils which are high in sodium, are saline, or are alkaline, usually are not satisfactory for rice production. Rice does best on soils that are slightly acid. If streams or other sources of irrigation water becomes contaminated with sea (salt) water, rice plants may be damaged. Rice can tolerate somewhat higher concentrations of salt as the plants get larger but high concentrations may kill young plants and may cause sterility (lack of seed production) in older plants around flowering time. The degree of damage is partly dependent on soil type and on the variety being grown. Certain varieties possess more tolerance than others to adverse soil and water conditions. It may be possible to grow rice satisfactorily on problem soils that are somewhat alkaline by applying small amounts of zinc to the soil at the start of the growing season. Also, the application of ammonium sulfate as the source of early season nitrogen fertilizer may greatly benefit young rice plants growing on moderately alkaline soils.

Availability of Improved Varieties

Plants of different rice varieties (cultivars) range in height from about 60 to 180 cm. They may produce from one to many tillers or culms depending on such factors as plant spacing, variety or type, soil fertility level, available moisture, and pest and disease control. Each culm normally bears a terminal panicle that may contain as many as 100 to 150 grains which are enclosed tightly in a pair of hulls (or husks), the lemma and palea. At maturity the panicle characteristically is fully exserted from the sheath of the uppermost leaf (also called the "boot"), but in some cases it may be partly enclosed. Hull color may be light straw-yellow, gold, or a shade of red, purple, or brown. After the hulls are removed, the kernels (brown rice) of different varieties range from 3.5 to 8.0 mm in length, 1.7 to 3.0 mm in width, and 1.3 to 2.3 mm in thickness. Rice cultivars grown in the United States are classed as long-, medium-, and short-grain. The average length of brown rice kernels is 6.61 to 7.5 mm for long-grain, 5.51 to 6.6 mm for medium-grain, and 5.5 mm or less for short-grain types. The average length/width ratios are over 3, 2.1 to 3 and up to 2.1 mm, for long-, medium-, and short-grain types, respectively. Brown rice of certain varieties grown in other countries shows a wider range in kernel measurements.

Most people desire rice of a specific grain type or at least rice having certain cooking and processing characteristics. Rice varieties differ greatly in quality, including cooking and processing characteristics. The amylose starch content of milled rice is closely associated with cooking quality. For example, the typical long-grain varieties grown in the United States have relatively high amylose content and the milled rice cooks up dry and flaky and kernels remain separated. Typical medium- and short-grain varieties have lower amylose content and the kernels tend to stick together when cooked. Glutinous or waxy rice (sometimes called sweet rice) which is grown in some countries for special uses contains virtually no amylose. Several chemical and physical tests are used to accurately determine cooking and processing characteristics of rice varieties. Rice breeders work very closely with cereal chemists in well developed rice research centers to insure that new improved rice varieties have the desired quality characteristics.

The nutritive value of rice is very important and research investigations were started over 20 years ago by Adair and co-workers in Arkansas (U.S.A.) to breed for increased protein content in rice varieties. Research to improve the inherent nutritional value of rice, particularly with respect to protein content and quality, has been continued and expanded in Arkansas and at other locations in the United States, especially at the

USDA Agricultural Research Center at Beltsville, MD. In recent years, considerable emphasis has been placed on improving the nutritional quality of rice varieties at the International Rice Research Institute in the Philippines and other Rice Research Centers. To date, adapted experimental varieties and breeding lines have been developed which consistently average two percentage points (20 to 25%) higher protein content in the brown rice than the standard cultivars. Much research also is being conducted on lysine and other amino acids in the rice protein, including detailed feeding experiments to evaluate the nutritional value of the improved rice varieties.

Great strides have been made by rice breeders in developing improved cultivars with much shorter and stiffer straw. These variety improvement programs are cooperative with other agronomists, soil and fertilizer specialists, pathologists, physiologists, entomologists, and researchers in other related disciplines. This insures development of varieties that: are responsive to nitrogen fertilization; have desirable plant type including a high degree of resistance to lodging; have resistance to production hazards such as diseases, insects, and adverse soil conditions; and that produce relatively high and stable field and milling yields of rice with desirable cooking and processing characteristics.

During the past 15 years (sixties and early seventies), so-called semi-dwarf or short-statured, stiff-strawed, high-yielding varieties (HYV's) that respond to high levels of nitrogen fertilization have been developed in the coordinated breeding programs in Taiwan, Japan, The International Rice Research Institute in the Philippines, India, Thailand, Colombia, the United States, and perhaps elsewhere. The International Rice Research Institute used improved varieties from Taiwan, the Philippines and other Asiatic countries to develop high-yielding varieties and the accompanying "package" of fertilization and cultural practices that sometimes produce as much as 8,000 to 9,000 kg/ha of paddy, in contrast to the average of 2,000 kg/ha for most farming regions of Asia. Certain improved varieties developed in the U.S.A. and elsewhere which are somewhat taller than the "short-statured" types, produce equally high grain yields under certain conditions using somewhat lower levels of N-fertilization. However, these HYV's which are of moderate plant height usually are more susceptible to lodging than are the short-statured types.

It is possible that the very rapid increase in acreage of a single improved variety of a crop such as rice could be undesirable. An important danger arises when a large geographic area is planted to one specific variety. If an epidemic of a certain disease occurs to which that variety is highly susceptible, then damage from that disease may be devastating over much of that area. If, however, the large planted areas are divided among three or four different varieties of different genetic background and which have varying responses to major diseases or insects, losses to such epidemics should be much less severe.

In order to get maximum grain production, it has been found necessary not only to adopt the improved high-yielding varieties but also to employ the appropriate season of planting, the necessary density of plants per hectare, adequate fertilization and pest control, and prompt harvesting. Planting high-yielding cultivars without using improved cultural practices may be relatively useless.

In any given country or geographic area, it is important to grow only those varieties that are well-adapted to the area. Where possible, it also is important to grow varieties that have the proper grain type and cooking characteristics desired by the consumers.

Cultural Practices (Lowland Rice)

Rotations

Where and when it is economically feasible, it is desirable to rotate rice with other crops that are adapted to the area. Common rotations in the United States where rice is direct-seeded and only one rice crop is grown per year, include: rice-oats-soybeans, and sometimes lespedeza which may be overseeded in the oats; rice-soybeans-soybeans; 2 years rice- 3 years improved pasture, or other combinations of rice and pasture, either improved or unimproved. Pastures for grazing cattle are improved by seeding clovers or grasses into the rice stubble following combine harvesting and applying fertilizer to the pastures as needed.

In most rice-producing areas of the United States, crops are rotated because under continuous cropping the soil usually becomes depleted in fertility and in organic matter. The resulting deterioration of the physical condition of the soil makes preparation of a suitable seedbed very difficult. In addition, the soil becomes progressively infested with weeds and diseases that lower the yield and the quality of the rice.

At the International Rice Research Institute in the Philippines, Bradfield conducted intensive rotation experiments with transplanted rice. He alternated crops of rice with soybeans or grain sorghums and by using short-season varieties, was able to produce four crops that included two high-yielding crops of rice and two other crops in only slightly more than a 12-month period. Rotations that may prove satisfactory in other countries may include other crops such as wheat, maize, food legumes, groundnuts, and vegetables.

When it is necessary to grow rice on land continously, it is very important to follow all possible measures for controlling weeds, diseases and insects. Working all remaining rice stubble or weed growth into the soil or mud following harvest so it will decay usually helps to control these pests.

Land Preparation

In countries where large fields are used and rice is direct-seeded for mechanized production, proper seedbed preparation is very important. Good drainage is necessary so that dryland equipment such as plows or disk-plows of various types can be used to at least partially turn under crop residues or incorporate them into the soil immediately after harvest. After the field has been left for 2 or 3 months during cold weather to allow time for the crop residues to decay, the land is again worked with disk-harrows, spring-tooth harrows, field cultivators or other similar implements to break up any clods and destroy any vegetation present. Then the field is worked with land-levellers or land-planes to fill in any low places. The soil surface is made as level as possible to provide good drainage and to aid in careful control of water depth when the field is flooded. A uniform but shallow depth of flood water (5 to 10 cm) is desirable for best results with improved short-statured varieties.

Where the crop is to be transplanted from seedling beds, a well-prepared field or paddy should have the following characteristics: (1) mud and water should be thoroughly mixed, (2) weeds, rice straw and stubble or other crop residues which were plowed under should be thoroughly decayed, and (3) land should be well levelled and puddled. Careful levelling is important for uniform distribution of irrigation water in the paddy. (Detailed instructions for production of rice seedlings are given in a booklet dated 1972 by The International Rice Research Institute, P.O. Box 583, Manila, Philippines, entitled "Tropical Rice Growers Handbook - Production of Seedlings." General recommendations for growing transplanted rice are presented in a "Rice Production Manual" compiled by Rice Information Cooperative Effort - R.I.C.E. - Univ. of the Philippines College of Agriculture in cooperation with I.R.R.I.). The rice fields should be kept wet and can be worked with recently developed small tractors and specially developed equipment or with the more traditional equipment and animal power.

Seed and Seeding or Planting

Care should be taken to use the best seed available of varieties that are well adapted to the area where the crop is to be grown. Important factors are genetic purity of the variety, freedom from mixtures of other varieties and weeds, and seed with low moisture content and high germination. These items should be considered both for direct seeding and for seedbed production of seedlings to be transplanted. Methods of growing the seedlings include: (1) ordinary wet-bed where seeds are sown on raised beds with drainage ditches between -- if soil is fertile, nitrogen fertilization may not be needed -- where needed, nitrogen is worked into the soil prior to seeding; (2) dry-bed method where water is limited and raised beds are prepared dry with canals between beds -- pre-germinated seed is sown evenly over the bed and covered with fine sand; (3) "Dapog" method (used extensively in southern Luzon, Philippines) may be used where water is abundant -- the surface of the slightly raised seedbeds is covered with banana leaves, empty cement or fertilizer bags, sheets of plastic, or small concrete slabs -- pre-germinated seed is sown thickly and water is splashed on the developing seedlings twice a day for 3 or 4 days - then the seedlings are flooded to a depth of 1 to 2 cm for 10 to 14 days after which they are ready for transplanting in small clumps. If the "dapog" method is used, often 5 to 10 seedlings may be planted per hill but with other methods and older seedings, 2 to 4 seedlings per hill are sufficient.

Fields for transplanting should be cultivated thoroughly and carry a shallow flood so the seedlings can easily be thrust into the soft mud. Hills of seedlings may be spaced 20 x 25 cm. Closer spacing is desirable where improved cultural practices are being used. Satisfactory field preparation for transplanted rice usually involves an initial flooding to soften the soil, and repeated cultivation (by hand, animal-draw, or power-driven equipment) to incorporate all vegetation and preplant fertilizers. Perennial weeds are thus destroyed and insect pests are greatly reduced in numbers by the thorough soil preparation.

Rice may be direct-seeded with mechanical drills which distribute the seeds uniformly in shallow rows that are covered with soil as part of the seeding operation. Often a heavy metal roller is used to make the seedbed more firm and to help conserve moisture. Other methods include broadcast-seeding of dry seed by airplanes, by hand, or by special ground equipment on a prepared seedbed that is dry or a prepared seedbed that has recently been flooded to a depth of about 10 cm. Where seed is to be broadcast into the water, the seed may be pregerminated for 24 to 36 hours immediately prior to seeding by airplane or other means. When appropriate materials and methods are available it is advisable to treat the seed with a recommended fungicide to help insure better stand establishment.

Where rice is to be direct-seeded, it is necessary to choose a suitable variety, and an ample supply of irrigation water must be readily available. Suitable and effective means also must be available for controlling weeds and insect pests. Suggested seeding rates for low-tillering varieties range from 90 to 120 kg/ha of seed where rows are spaced 15 to 25 cm apart; for high-tillering varieties, a 60 to 80 kg/ha rate should be adequate. If the germination percentage of the seed is less than 80%, then the seeding rate should be increased proportionately to produce an adequate stand of plants. Research in Arkansas (cooperative U.S. Dept. of Agr. and Arkansas Agr. Exp. Sta.) showed that 150 to 300 rice seedlings per square meter was a desired stand. However, 50 plants of barnyardgrass per square meter competing throughout the growing season, reduced grain yields by nearly 50%. Fairly satisfactory grain yields may be obtained with somewhat fewer plants if weeds are controlled and ample and timely nitrogen fertilizer applications are made.

Fertilization

Proper balance of the major fertilizer elements (potassium, phosphorus, and nitrogen) is necessary for top production by the new, so-called, high-yielding, rice varieties. These improved varieties, especially the short-statured, stiff-strawed or non-lodging types, usually respond well to rather high levels of available nitrogen. Newly cleared woodland may be high in native nitrogen but most of this nitrogen is utilized by the first two or three rice crops. It then is necessary to provide the needed nitrogen through green manure crops, which are turned under into the soil, or by application of commerical fertilizers. Ammonium sulfate and urea are the most satisfactory commercial nitrogenous fertilizers for application early in the growing season. Anhydrous ammonia is fairly satisfactory for preplant applications in lowland rice production if it is applied to a sufficient depth (10 to 15 cm) and sealed in the soil so it does not escape to the atmosphere. Other forms of N-fertilizer such as ammonium nitrate and liquid solutions of N may be satisfactory sources for midseason applications. Plants of responsive rice varieties require moderately high levels of N early in the growth cycle for establishment of a good root system and for tillering. The other peak period of need for N is early in the reproductive stage of growth when the panicle starts to develop and begins to form the grain. If N-fertilizer is applied late in the vegetative growth stage, excessive stem growth and elongation usually follows and severe early lodging may result. Delaying midseason N application until after stem elongation has started, usually results in less straw growth and reduces chances for severe lodging. Under lowland rice production, proper water management is very important to prevent loss of nitrogen from the soil.

Only relatively low levels of N-fertilization can be tolerated by local or indigenous varieties which generally lodge badly with even moderate levels of N. In contrast, relatively high rates of N-fertilizer are necessary to boost the yields of improved, short-statured, responsive varieties up to 7 to 8 metric tons (7,000 to 8,000 kilos) of grain per hectare. However, many of these improved varieties will produce as much grain as local varieties when low levels of N-fertilizer are used on both.

When high total rates (above 100 kg/ha of actual N) of N-fertilizer are used on the HYV's, it usually is advisable to divide the total amount into three applications. Applying 40 to 50% of the total N early in the season and the remainder in two equal increments at midseason helps prevent excessive vegetative growth which tends to make rice plants more susceptible to several diseases. Research in Arkansas (U.S.A.) showed normally grows to a moderate plant height (115 to 125 cm), proper timing of the midseason N-fertilization reduced plant height by 18 cm, reduced lodging from 69% to only 2%, and increased grain yield from 5,700 to 7,900 kg/ha. For best results from rather high rates of total N, the first midseason application should be made when the first elongating internode of 50% of the main stems of a given variety reaches a specified length. For the popular, stiff-strawed, Starbonnet variety this length is about 12 mm whereas for other varieties with somewhat less lodging resistance, the specified length is about 37 mm. This usually corresponds to the time when the developing panicle is about 2 mm long. A few main stems are split open with a knife to determine stage of plant development. The second midseason increment of N-fertilizer should be applied about 10 days after the first midseason application. On large, direct-seeded fields, these midseason applications are made from airplanes without draining the irrigation water from the fields.

Part, if not all, of the phosphate and potash needs of lowland rice may be provided by the incorporation of animal dung, composts, green manures, and crop residues of previous crops that are incorporated into the soil during seedbed preparation. Where available and needed, applications of commercial potash and phosphate fertilizers may be worked into the soil prior to seeding or transplanting.

Pest Control

Control of weeds, diseases, and insect pests of rice are necessary to reach satisfactory levels of production in any type of rice culture. Planting rice in rows facilitates the use of small weeding devices and hand applications of chemicals to control important pests. All types of rice pests tend to be more abundant on land cropped continuously to rice but their abundance can be reduced substantially when rice is rotated with other crops, especially row-crops, in which weeds and other pests are controlled. Weeds compete with rice plants for nutrients, sunlight, and moisture and should be removed or controlled early in the growing season to avoid severe yield reductions. Disease organisms, rodents, and insects may live and multiply in crop residues or weeds and trash at the edges of fields. Clean cultivation will help to keep harmful insect and rodent populations to a minimum. The growing of varieties that are resistant to specific diseases and insects helps to reduce the abundance of these pest organisms. Rodents and birds sometimes damage the rice crop severely and they should be controlled insofar as possible.

Insects which can prove very harmful to rice production in various parts of the world include the gall midge, several species of stem borer, the green leaf hopper and brown plant hopper which are vectors or carriers of virus diseases, the rice water weevil, and the rice stinkbug. Partial to sometimes almost complete control of some of these pests may be provided by using good agronomic practices, timely applications of suitable insecticides, and growing resistant varieties, when available.

Diseases which can be very damaging include blast, which may be especially severe in upland rice, tungro virus and other viruses which may be very severe in some rice-growing countries, bacterial leaf blight, and several other seedling, foliar and stem diseases. Effective control of these diseases depends on the use of good agronomic practices, including timely but not excessive applications of N-fertilizer, breeding for resistance as new varieties are developed, and, in some cases, chemical applications to control the disease organism or the insect vector.

Weeds in rice fields may best be controlled by a combination of practices including thorough preparation of the soil prior to seeding or transplanting the rice, timely application of suitable chemicals, clean cultivation of rice growing in rows, and hand weeding. Control of weeds in other crops grown in rotation with rice also is very important. The use of herbicides for weed control has greatly increased in recent years. However, it is very important to use suitable rates and timing of specific herbicides that will kill the weed species present without severely or permanently damaging the rice crop or adjacent fields of other crops. A very recent development in methods of controlling specific weed species is the control of northern jointvetch (curly indigo) in rice fields by spraying millions of artifically propagated spores of the organism which causes an anthracnose disease on the weed. The method was developed by Smith and co-workers in Arkansas (cooperative research, U.S. Dept. Agr. and Arkansas Agr. Exp. Sta.). The disease organism has not affected numerous other weed and crop species tested to date.

Weeds and insect pests and diseases that are serious on rice, vary greatly from region to region. It is highly essential to identify a potential outbreak of important pests as soon as possible, so that treatments for their control can be used on each pest at its most vulnerable stage.

For further information on Crop Protection, see Chapter 4 in the book -- "Tropical Agriculture" by Wrigley. (Reference list following Chapter 40).

Upland Rice Production

Upland rice is sometimes termed "dry-land paddy", despite the fact that successful non-irrigated rice culture is largely confined to regions where rainfall during the growing season is such that the soil is continuously moist. Rice is a heavy user of water, and upland rice will yield well only with abundant rainfall. Regions having periods of 4 to 6 months with 130 to 180 millimeters of well distributed rainfall each month, have a potential for satisfactory upland rice production. Rice does not tolerate dessication, especially during flowering, at which time the panicles are emerging from the boot or sheath of the flag leaf (uppermost leaf) and pollination of the florets are taking place.

Soil type is an important factor in upland rice production since it affects the soil's moisture holding power. Deep soils that permit extensive root growth and have the texture and structure to receive and hold substantial amounts of rainfall, usually are most productive. Rice has an advantage over other upland cereal grains in being more tolerant of acid soils and less sensitive to occasional water-logging.

Upland rice is suited for crop rotation systems which include other staple crops such as an oilseed crop, cassava, taro, maize, sorghum, and legumes. The alternate crops are grown in seasons of lesser rainfall. Upland rice is classed as a soil erosive type of crop on land with 5% or greater slopes, but erosion may be controlled by the same measures as those that are effective with maize, sorghum, and millet (See Chapter 4). The maintenance of soil productivity may be enhanced by a regular sequence of a forage or fodder crop alternating with the tilled crop, where such feed crops would support a livestock enterprise. Forage crops aid in suppressing annual weeds; they also contribute organic matter when turned under, and the forage crop root systems tend to improve soil structure and general soil fertility.

The fertilizer needs for upland rice must be evaluated in terms of moisture availability as well as inherent soil fertility. Nitrogen is the major nutrient requirement, and fertilizers carrying nitrogen as ammonia compounds are preferred. Addition of phosphate and potash fertilizers may be needed on upland soils, but amounts required are less than for nitrogen. The amount and types of fertilizers needed to produce high rice yields should be determined by field research on representative soil types, or if such research is lacking, by laboratory tests on representative samples of field soil to estimate phosphate, potash, and nitrogen needs. Under generally favorable, high-moisture conditions, with high-yielding varieties good cultural practices, and adequate pest control, upland rice may respond to nitrogen fertilizer rates of 40 to 80 kg/ha of elemental N. When available animal manures up to 20 metric tons per hectare may replace part of the commercial fertilizer. Under upland rice production it may be necessary to distribute several rather small applications of nitrogen fertilizer during the growing season to obtain satisfactory grain yields.

The varieties best suited for upland rice culture may not be the same as those that are most productive on wetlands but many of the new improved lowland varieties also outperform indigenous varieties under upland conditions. Less breeding work has been done specifically on upland than on lowland (wetland) rice but a considerable number of improved varieties which produce reasonably well on upland fields are known to researchers in various countries. An initial, well-planned field performance test should be conducted to determine adaptation and yielding ability of all available improved varieties, as a prelude to selection of one or two superior varieties for a specified region. In a given area varietal responses may differ greatly and choice of a variety may profoundly affect economic returns.

Upland rice is best seeded in rows for convenience in weed control, for treatment of pests, and for harvest. Spacing between rows may vary from 35 to 50 centimeters. Suitable seeding rates range from 100 kg/ha for low-tillering varieties, to about 70 kg/ha for high-tillering varieties. The more productive soils will support heavier rates than sandy or other less productive soils.

Harvesting and Threshing

Traditional harvesting of rice has been done by hand, and in some places each panicle was cut off separately with a small knife. The use of hand sickles has increased and, while still laborious, permits selective harvesting of small areas in fields of the older indigenous varieties which may ripen unevenly. With the newer varieties and improved cultural methods involving thick stands of plants that ripen more uniformly, machine harvesting has become feasible. Prompt harvesting of the ripened crop, followed by immediate land preparation and planting of the next crop often makes it possible to grow two to three crops of rice or other desired crops per year on the same land, where water supply and seasonal weather is favorable.

When the rice crop is cut with a sickle, the harvested stalks and panicles are spread out to dry in the sun. After a short period of drying the rough rice or paddy (the grain with enclosing lemma and palea) is threshed. In some areas and under some conditions, the rice stalks are tied in bundles and, after some drying takes place, these are placed on drying racks or in small shocks or stacks to be left for later threshing. Better quality rice and less kernel breakage occurs if threshing is completed within a few hours after cutting.

Direct-seeded rice which is mechanically harvested usually is cut at a grain moisture content between 18 and 21%. The large combines which generally cut a swath 3 to 4 meters wide have powerful tractor engines to propel the big wheels of the combines over the often muddy soil. In addition, the same or a supplementary power unit, operating through a series of drive belts and pulleys, turns the cylinders for threshing the grain, drives the shakers to separate the grain from the straw, and elevates the clean grain into a temporary bin on the combine. Grain is unloaded from this bin by a power-driven, screw-type conveyor into a larger bin on a grain cart which is then pulled by a tractor to the edge of the field. This grain cart is similarly emptied into a large truck which then is used to haul the grain to a large commercial dryer. Artificial drying within a few hours following harvest is needed to reduce the moisture content to about 14% for safe storage.

Hand harvesting rice may be threshed by driving cattle slowly over a hard floor on which sheaves of rice have been laid, to separate the paddy from the stalks. A more satisfactory practice is to beat the sheaves of the crop against a block of wood, or a threshing ladder standing in a tub to collect the grain. Machine threshing has become increasingly common, using a variety of machines, which have cylinders or drums with projecting pegs that act as flails to beat the paddy from the stems. Hand or foot power for these machines is being replaced by small engines in more advanced rice growing regions, and new types of small threshers are being designed and manufactured.

Winnowing to separate the grain from chaff is predominantly done by hand when the wind is blowing, by tossing the grain into the air so that lighter weight foreign matter is carried beyond the pile of grain. Modern threshing machines include adjustable air blasts to accomplish winnowing, after separation of straw from the grain by screening.

Drying and Storage

Freshly threshed rice may spoil rapidly when exposed to high temperatures, high moisture content, molds, and foreign matter. Prompt cleaning to remove all straw, chaff, joints, and weed parts will speed drying and lessen danger of spoilage and insect damage. Threshed grains generally are sun-dried on concrete or other hard surfaces, or in grain dryers. When grain is dried artificially, it must be dried slowly at first. From an initial moisture content of 18 to 21%, the paddy should be gradually dried down to about 13 to 14% moisture. Rapid drying causes checking or cracking of the kernels, thus producing an excessive percentage of broken kernels when the rice is milled. To avoid damage from artificial drying, the ambient air temperature should not exceed 120 F (49 C). Moisture can be removed from the grain by a series of passes through a batch dryer or a continuous flow dryer. After the moisture content has been reduced to about 16% moisture, and proper facilities are available rice may be further dried while stored in on-the-farm aerated bins with artificial heat added. The safety of such storage and the amount of drying possible, depends on the temperature and moisture content of the outside air being forced through the grain.

Rice can be stored satisfactorily in the hull (paddy) after it is dried to 13 to 14% moisture, but special precautions are needed to prevent insect and rodent damage. Higher moisture content fosters growth of molds, results in kernel discoloration, and accelerates any insect infestations. Officially approved insecticides that are not hazardous to the ultimate consumers should be used to protect the grain from stored grain insect damage.

Milling and Processing

The modern milling process removes the hulls, removes the bran layer from the brown rice, and polishes the milled kernels in successive stages so as to produce a high proportion of whole kernels. Milling the grain at 13 to 14% moisture is preferred over higher or lower moisture contents. Commercial mills are generally capable of producing a total milled rice recovery equal to about 65% or more by weight of the original paddy.

Milling yields may average 45 to 60% head rice (whole to 3/4 whole kernels), 10 to 20% broken grains, about 3% brewers rice (small broken kernel pieces), and about 18% rice bran. The primitive types of rice mills still widely used on rice for home consumption, dehull and polish the grain in one operation, but produce a higher percentage of broken kernels and waste much of the bran. The by-products of commercially milled rice (brewers' rice and rice bran, etc.) have substantial market value, and these products make commercial milling more attractive economically.

In some cases, particularly in Japan, much of the rough rice (paddy) is shelled (hulls are removed) and the resulting brown rice is stored until just before it is to be consumed. Then it is milled and used as freshly milled rice. Kernels of rice that have been freshly milled tend to stick together more when cooked than do kernels of the same type rice that has been stored after milling. Usually it is the short- or medium-grain type rice that is consumed as a freshly milled product. Long-grain rice of typical quality for consumption in the United States (U.S.A.) usually is stored for several months as milled rice before being sold to the consumer. The kernels of this rice prepared in boiling water cook up "dry and fluffy" and individual kernels maintain their identity even after cooking. This is in contrast to the short- and medium-grain types that tend to form clumps after cooking.

People in different countries prepare rice in various ways but, in general, a certain type of rice which can be cooked in a specific way usually is preferred by any one group.

Marketing

The majority of the rice crop produced annually, in most parts of the world, is consumed in the same area where grown. Recently, additional countries have started exporting rice in years when their total production has been sufficiently high. Usually this has necessitated developing some type of grading system and formation of farmer cooperatives or governtal agencies for orderly processing of the crop. This also requires the constructing of suitable drying and storage facilities and development of a satisfactory and manageable marketing system.

In the United States (the leading rice exporting country), a detailed system of government rice grading and an extensive network of commercial driers, mills and processors has been developed. Rice may be shipped by huge trucks or in railroad cars to seaports for transporting to other countries throughout the world. A worldwide system of brokers handle many of the details of buying and selling the rice. In other countries, much of the movement of rice is under supervision of government representatives.

Economics of Rice Production

The main advantage of the use of improved technology and the growing of improved, well-adapted varieties that are short-statured, non-lodging, and high-yielding, is the greatly increased total yield per hectare over that of traditional rice production. These yields may be as much as 2-to-4-fold greater than from traditional production methods and varieties. An even more revealing estimate of advantage is the actual total cost of production per metric ton of milled rice. However, an additional factor of some significance to the rice grower is the feasibility of utilizing the improved technology to carry out multiple cropping (2 to 4 crops per year), either with successive rice crops or growing other crops in rotation with rice. The net effect should be that of increasing total yearly farm income. In addition, production of additional food crops can increase the types of food available and can result in improved nutrition for the people.

In the Philippines, the International Rice Research Institute has made detailed studies, of which only a few key data are cited here: single cropping with rice by traditional methods produced only 1/5 of the net returns achieved by double cropping with improved technology using superior varieties on irrigated fields. With rainfed rice, use of improved culture and varieties doubled net returns to the growers. In these studies, the sizes of the farms were large enough to fully utilize the labor of the operator and his family. It should be noted that yields per hectare were increased about 3-fold from use of improved culture and varieties, to produce doubled net returns from marketable rice. These yield increases were made possible by growing varieties that were non-lodging and resistant to major insect pests and diseases and that respond to heavier nitrogen fertilization. Land preparation, planting, weed control, harvest, threshing and drying were effectively handled. The net result was to produce a larger crop and to preserve a higher percentage of that crop for market. It is obvious that in order to increase net returns, all labor and materials used should produce increases in net crop value substantially above the total costs of such labor and materials. It is essential that all practices and materials be carefully evaluated as to their contributions to net crop values, and to concentrate on those that increase final returns with less than proportionate costs.

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CHAPTER 6

MAIZE 1/
(Zea mays)

Maize As A Food Crop

Maize or corn as it is commonly referred to in many parts of the world is widely used as a food crop in the tropics and subtropics; it has the heaviest usage in Latin America on a per capita consumption basis; but Africa follows closely despite the expanses of drier climatic zones where sorghum and millet are better adapted than maize. Maize production also assumes major proportions in the Asiatic countries of India, Indonesia, Pakistan, Philippines, Thailand, and Turkey. Rice replaces maize on wet lands of the tropics and subtropics, and wheat competes with maize as an important cereal in many regions as an irrigated crop in the dry season.

Maize is a food crop that is rich in starch or carbohydrates, averaging about 71% on a worldwide basis, but comparatively low in protein (9.5%). The germ contains nearly all of the oil and approximately 20% of the whole kernel proteins. The germ protein is of good nutritional quality whereas the endosperm protein is deficient in two essential amino acids, lysine and tryptophan. Thus, when maize is prepared for food, it is more nearly balanced nutritionally if the germ is included in the final product. Being largely starch, maize grain is an energy food. It should be supplemented with protein foods, such as animal products and grain legumes or oilseed meals, and with other foodstuffs to supply vitamins and minerals to produce a balanced human diet.

In recent years, a mutant form of maize (opaque-2) in which the kernels have a floury endosperm has been found to be much higher than common maize in content of two nutritionally essential amino acids - lysine and tryptophan. Nutritional studies with malnourished children show that "high-lysine" maize is a much more satisfactory food than common maize and will largely prevent the occurrence of the nutritional diseases - kwashiorkor and marasmus. Intensive breeding programs to transfer this trait to varieties for general use are now under way in a number of countries, and high lysine types are commercially available in some, as in Brazil, Colombia, the United States, Vietnam and the U.S.S.R.

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Maize grain enters into livestock feeding only to a limited degree in Latin America and Africa, particularly for pigs and poultry, and greater usage for this purpose may become feasible when total maize production increases beyond the amounts needed for human food. The following discussion focuses on maize as a food crop. It is highly important to substantially increase maize yields and thereby reduce costs per unit of crop. These improvements will permit growers to achieve greater net returns, provided prices are regulated to allow growers to benefit from enhanced productivity.

In the "Corn Belt" of the United States, average yields have been increased about three-fold since 1940, as a result of the development of high-yielding hybrids, and such associated cultural practices as adequate fertilizer applications heavier plant populations, pest control, and more efficient harvesting methods. Western Europe has adopted similar breeding methods and technology on culture, with similar results where all effective practices are combined.

The improvement of maize production, with attendant reduction in costs per unit of crop and the opportunities for improved net returns to growers, is moving into the tropics and subtropics. Some of the research and technology developed for corn production in temperate zones may be adapted to tropical and subtropical conditions. Other factors require adaptive or original research in the tropics, and progress in conducting such research is now under way in a considerable number of countries. The following pages undertake to consolidate the available information directly applicable to tropical regions, and to indicate some research approaches that are needed and should produce highly useful and usable results.

Ecological Adaptation of Maize

Maize thrives in warm sunny climates where moisture supply is adequate during the growing season. The occurrence of dry periods during the growing season may adversely affect the crop if soil moisture supplies are exhausted before rains recur. The most critical times in the growth period of the crop as to moisture needs occurs during the time of tasseling and pollination, but the period of kernel filling is also important. Sorghum and millet tolerate dry periods during the growing season better than maize and are generally more productive where rainfall is uncertain or characteristically limited during the cropping season. Some evasion of moisture shortages can be achieved by growing varieties with shorter growth periods that can be planted and matured before moisture shortages become acute. Also, selecting the deeper soils that have greater moisture storing capacity, and managing these soils to store rainfall most effectively, will permit maize production in regions where average rainfall on upland soils is inadequate for profitable maize yields.

Maize is typically adapted to soils of high fertility that are deep and well drained. The crop requires an abundance of nitrogen, and liberal amounts of phosphates and potash. It prefers soils of not more than moderate acidity, and having considerable amounts of calcium, magnesium, and sulfur. The crop is sensitive also to deficiencies in the trace elements, particularly zinc and boron. The limited evidence from tropical research suggests that on some highly weathered upland soils, some of the trace elements - copper, zinc, boron, molybdenum, manganese, and iron - may be in short supply for profitable corn production.

The soil depth is important from the standpoint of moisture supply to the plant during critical growth periods. Maize has the capability of rooting to depths of 1.0 to 1.5 meters on favorable soils. If the soil profile is at field carrying capacity to such depths at time of tasseling, maize will meet its moisture needs for 10 days to 2 weeks, without additional rain. Lacking such moisture reserves in the soil, maize yields may be severely reduced by short-term droughts. Maize roots cannot function or survive in waterlogged soils, and this crop is not suited to soils with imperfect internal drainage, even though not flooded at the surface.

Plant Characteristics

Maize is a coarse-leafed member of the grass family. It shows great variability between regional types and strains; stalk heights may range from 1 to 8 meters, and stalk diameter from 1.5 to 4.0 cm. The stalks are filled with pith, which serve as the storehouse for food produced in the leaves prior to translocation to developing kernels on the ear. There may be several to no tillers for each main stalk, but production of ears occurs mostly on the main stalk. The stem (stalk) is jointed with one leaf borne at each node, and a bud at the base of each internode within the leaf sheath that clasps the stalk. One or more of these buds develops into an ear shoot which bears the ovaries which develop into kernels after pollination. Each ovary has a long style ("silk") that protrudes beyond the modified leaves that form the husks of the ear, and pollen falling on the silks germinate and grow through the styles until they reach the ovaries and cause fertilization. The tassels borne at the top of each stalk, produce pollen only, and this pollen is blown onto the silks of neighboring plants.

Maize is a highly productive crop, largely because of the abundant leaf growth, and the high level of photosynthetic activity in the leaf. Not only is there a large amount of chlorophyll bearing tissue in the leaf blade, but all vascular bundles in the leaf are sheathed with such tissue. After the plant reaches full size, the photosynthetic products (sugar, starch, and nitrogenous compounds) are stored in the leaves or stem until pollination of the ear occurs, after which these materials are transferred to the developing kernels.

Maize Breeding

Maize is a completely "cross-pollinated" species, and the kernels from a single ear will produce plants having considerable variability in plant and ear characters. Maize pollination is facilitated by having the male flowers in the tassel and female flowers in the lateral inflorescences (ears), but breeding programs to concentrate desirable hereditary traits into single strains requires man's control of pollination and fertilization in every plant generation.

Inbred lines of maize are produced by continuous self-fertilization (transferring pollen from the tassel to the silks of the same plant) accompanied by visual selection for vigor, disease and insect resistance and such quality traits as may be of local importance. After 3 or 4 generations of self-fertilization, the lines have become stabilized, each line having its own distinctive appearance. These lines are then evaluated in hybrid combinations either as top-crosses (Inbred x Variety) or single crosses (Inbred A x Inbred B). The great majority of each test-cross hybrids will exhibit no marked improvement over the locally grown varieties. A very small percentage of the test-crosses will exhibit sufficient merit (productivity, insect and disease resistance, etc.) to justify additional testing. Finally only the very best of these hybrids will be recommended for commercial production.

When superior hybrid types have been created, seed must be produced each plant generation by excluding all foreign pollen, and insuring that only the desired parents are involved in each seed crop. In the major maize growing regions of temperate zones, hybrids between selected inbred lines, that have proven productive, are in commercial plantings. However, in several tropical regions, an accelerated breeding program that used hybrids between selected races has produced highly productive varietal hybrids. Thus in Kenya, a hybrid between a selected Ecuadorean collection and a specific East African variety proved to be highly productive, and has become widely grown throughout eastern Africa above 1600 meters. Continuing plant selection within each parental variety has further enhanced the productivity of the varietal hybrid.

Reasonable success has been achieved also in producing "synthetic" strains of maize by intercrossing several races found to produce superior variety crosses and allowing these to cross pollinate. Growers may save their own seed of "synthetics" for a few years with only slight losses in vigor except through contamination by outcrossing to unimproved local strains. It should be emphasized that superior synthetics are produced only by extensive testing of the races and lines to determine which ones may be combined to produce the desired results. Then these varieties should be selected for higher yields and better agronomic characters by the maize breeder. These new selections may be released at periodic intervals after their merit has been demonstrated. Under this system, a farmer might be expected to receive new seed of an improved type every third or fourth plant generation.

Except for use of specially designed synthetic varieties where farmer selected seed may be used, all planting seed should be that produced by seed growing organization, meticulously monitored by inspection agencies. This is needed to insure that the production of seed has been handled so as to retain its identity, and that cross pollination has followed the procedure known to produce the hybrid vigor of designated crosses. Moreover, the seed should have high germination, and have been treated to control insects and diseases that attack germinating seeds and seedlings. The cost of good seed is but a small part of the total cost of growing a maize crop, but it often constitutes a controlling effect on ultimate yield.

Field testing of available hybrids or synthetics in important maize growing regions, to determine the most productive types, is a service that government or other public agencies should provide to maize growers. These tests should be conducted with the cultural practices adapted to the soil and climatic conditions that prevail, that permit full expression of yield potential.

Although many superior maize hybrids have been developed for the United States and Western Europe, virtually all of these have proved unadapted and inferior in the tropics and subtropics. Dependence must be placed on breeding programs conducted in the regions to be served.

Excellent breeding programs are underway throughout the tropics and subtropics. Superior breeding populations have been developed and are under selection for even greater superiority. These can be released as synthetic varieties or used as parents for variety-cross hybrids. These varieties and hybrids have a wide range of adaptability within altitudinal zones.

The nutritional superiority of high-lysine maize has been well established. The substitution of high-lysine for normal maize would be desirable in all areas where maize provides a substantial portion of the protein and caloric intake. However, the development of acceptable high-lysine types poses several breeding problems. High-lysine maize is typically characterized by a floury endosperm texture which is associated with a reduced kernel weight and therefore lower yield, and some increase in susceptibility to ear-rots and to damage by stored insect pests. Each of these undesirable properties could be corrected or minimized by the development of high lysine types with normal or near normal texture.

A large number of genetic factors exist which modify the floury texture of opaque-2 in the direction of normal texture. Unfortunately, some of these modifiers also reduce the percentage of lysine and tryptophan to near normal levels. Under such conditions, reliance in maintaining the desirable chemical properties must be based on either colormetric or amino acid analyzer verification. Considerable success has been achieved in both Colombia and CIMMYT in developing harder-textured, high-lysine types. Complete yield comparability has not yet been achieved, but it appears this should eventually be possible.

Maize Culture

Seed Bed Preparation

Maize is customarily planted on land that has been tilled to incorporate any crop residues on the field, as well as animal manures that are applied and to destroy perennial weeds. The tillage should leave the soil surface somewhat roughened to facilitate penetration of rainfall and to minimize runoff and erosion losses. Beyond these requirements, tillage of the land appears to have minimal effect on ultimate yields. It is important to have mellow, moist soil in which to plant seed, so as to stimulate prompt germination and rapid establishment of seedlings.

Plantings should be made in rows for convenience in weed and pest control, and for harvest. Rows should run across the prevailing slope of the land, following contour levels, to retard runoff and minimize soil erosion losses. Row spacings are generally 70 to 100 centimeters.

Fertilizer is best applied in the rows, preferably to one side and below the level of the seed, but not in direct contact with it. Since many tropical soils have excessive phosphate fixing power that converts fertilizer phosphorus into inert, insoluble iron and/or aluminum phosphates and since the movement of phosphates is negligible, broadcasting phosphate fertilizer is generally a wasteful practice. Phosphate and potash fertilizer should be positioned in the soil, below and slightly to the side of the seed. However, nitrogen fertilizers may be broadcast without loss in effectiveness since they enter the soil with the rains and remain soluble in the soil moisture. Where other factors are not limiting, 150 kg of nitrogen (N), 50 kg of phosphate (P_2O_5), and 150 kg of potash (K_2O) per hectare must be available to support grain yields of 7 metric tons per hectare. The amount of chemical fertilizer to be applied to each field should be adjusted to recognize two factors: (1) the projected maize yield that appears attainable in the locality, and (2) the current level of fertility in the soil as determined by observed responses in fertilizer trials and by soil tests. Fertilizer should be supplied in amounts needed to augment soil fertility as needed to produce desired yields and animal dung may be substituted for part of the fertilizer. With hand planting of seed, a shallow furrow should be opened, the fertilizer should be placed first, covered about 2 cm deep with soil, then the seed dropped and covered with 2 to 4 cm of soil.

Plant densities should be adjusted to fully utilize soil fertility and moisture supply, and the productive capacity of the hybrid or synthetic. Excessive densities on infertile soils or those with limited soil moisture at critical growing periods will actually reduce final yields. Thirty thousand plants per hectare (100 cm by 33 cm spacing) may provide full occupation of less productive soils, whereas a maximum of sixty thousand plants per hectare (70 cm by 24 cm spacing) may be needed to fully utilize highly fertile soils where moisture is abundant.

Time of planting in regions that have wet and dry seasons has proved to be very important. Early planting either immediately before rains are expected to begin, or promptly after the first rains, characteristically produce highest yields. The causes of reduced yields with delayed planting are complex and not fully understood. Availability of nutrients as affected by soil temperature, moisture and aeration is involved. The response to nitrogen fertilizer is much less in late planted than in early planted maize. Pests can further reduce yields as they are usually more serious on late plantings. Whatever the true reason, the advantages of early planting are well documented, and the farmer can easily plan his operations to take advantage of this situation. No specific recommendations are made herein on treating seed with appropriate fungicides and insecticides before planting, since such treatments must follow in-country regulations.

Cultivation

The principal function of cultivation is to control weeds. However, weeds may be suppressed by hand pulling, hoeing or cultivating, or by application of appropriate herbicides. These various methods are effective only to the extent that weeds are killed early before they damage the maize plants by competition for soil nutrients and for soil moisture. Damage to the maize plant root system from weed competition may be halted but not corrected when the weeds are killed. If removal of the weeds damages the root system of the maize plants, crop yields will be severely affected. This is particularly true if weed removal is accompanied by shortage of soil moisture that prevents regeneration of the damaged crop root system.

Weed control by application of appropriate herbicides is effective, and avoids physical damage to the crop root system, but the cost is substantial and each herbicide must be used as prescribed by the manufacturer. Different species of weeds require the use of appropriate herbicides; sometimes mixtures of two or three are needed to cope with all species. A few herbicides leave a residual toxicity in the soil that affects other succeeding crops. Chemical control measures for weed control usually produce the greatest benefits when applied while weeds are still small or before germination.

Pest Control

Insects, diseases, and birds are always troublesome and may be decisive in effects on yield. Where feasible, the most useful control measure is the development and use of synthetics or hybrids that are resistant to specific pests. As mentioned earlier, prompt planting is often useful in evading the most severe depredations. Growing maize on the same land in successive years tends to build up damaging populations of the pests. A seasonal rotation of crops to other fields may be quite useful.

Further defensive measures may be possible, but these must be developed to combat the specific pests that are present in the light of their individual characteristics. It cannot be assumed that the same pests attack maize wherever the crop is grown. Also, in some cases, apparently similar pests may have different life histories and have to be combated by different means. The common diseases include leaf blights, rusts, smut, mildew, virus and rots of the root, stalk and ear. These diseases are more serious when humidity is high. The parasitic witchweed can reduce yields under certain environmental conditions. Serious insect pests include cutworms, wireworms, budworms (earworms), stem borers, root worms, chinch bugs, aphids, and leaf eating insects. Storage insects include weevils and grain moth.

Because of the large interactions between time of planting, improved varieties, fertilizers, weed control, plant densities, and pest control, all inputs and improved cultural practices must be adopted simultaneously for economic increases in maize production.

Maturation and Harvest

The maize grain crop is mature when the kernels reach the "hard dough" stage. The time of physiological maturity is accurately determined by the development of the "black layer" at the point of attachment. Translocation ceases when this black layer forms. From this stage onward, ripening consists of moisture loss, which may be quite rapid if the weather is dry. When fully cured, maize kernels should have 10 to 12% moisture as the grain will store without molding at this moisture content. If birds or other pests cause serious field damage to ripening corn, the crop may be harvested at the hard dough stage and dried under protected conditions.

Pests of Stored Grain

The greatest hazards to stored maize are (1) molding when moisture content is too high, (2) insect damage - grain weevils, grain moth larvae, and meal worms, and (3) rodents. Grain infesting insects are often brought in from the field at harvest, or they may remain in storage areas from season to season. Storage losses are heavy in warm climates and damage may be serious in relatively short periods. Treatment of the empty storage areas, and treatment of all grain as it enters storage irrespective of apparent infestation, is necessary and relatively inexpensive. Infested empty storage areas and empty containers may be disinfected with a weak solution of malathion, an insecticide that is rapidly degraded and leaves no toxic residue.

A widely used fumigant for treating grain to destroy insects in commercial storage is methyl bromide. This chemical should be used at the rates and in the manner prescribed by the manufacturer. The grain should be placed in a closed storage container, and the solution applied to the top of the grain. The vapor from the solution is heavier than air and settles downward through the grain. The vapor is toxic to man and must be used with proper precautions. Another chemical for treating stored grain is less toxic to man and better suited to on-farm treatments. This is a mixture of three parts by volume of ethylene dichloride and one part carbon tetrachloride applied as a coarse spray or sprinkled on the surface of the grain. Even this mixture must be used with caution to avoid injury to humans. It should be used as prescribed by the manufacturer.

Although the fumes of methyl bromide and of ethylene dichloride-carbon tetrachloride are toxic to man, there need be no danger to the applicators if precautions are taken to avoid inhaling the fumes. Moreover, these chemicals leave no residue on the treated grain, and such grains are not damaged in their value as foodstuffs.

An alternate insecticide is malathion. Malathion is one of the most useful insecticides for treatment of grain and seed to be protected from insects attacking grain in storage. Emulsion sprays prepared from premium grade 57% malathion emulsifiable concentrate, diluted by adding 100 cc to 4 liters of water, and applied as a mist spray uniformly to 15 metric tons of grain, gives good protection for 2 to 3 months. It is essential that grain and seed be treated promptly as it comes from the field and enters storage. Also, retreatment will usually be necessary in 2 to 3 months to prevent insect multiplication, since malathion degrades and becomes harmless in a relatively short period.

All insecticides can be injurious to man and animals, unless handled carefully. Follow the directions and heed all precautions on the insecticide labels.

Keep pesticides in closed, well-labeled containers in a dry place. Store them where they will not contaminate food or feed, and where uninformed adults and children cannot make improper use of them. Promptly dispose empty pesticide containers; do not use them for any other purpose.

Special Storage for Seed

Seed storage in warm humid climates is a problem for all types of crops. However, research has shown that good viability is retained for one year when seed is promptly dried at harvest time to a moisture content of 8%, and maintained at that level or less, for the storage period. The viability is retained for much longer periods if the dry seed can be stored at temperatures of $10^{\circ}C$ or lower. This would be important for planting seed to be held two years or longer.

CHAPTER 7

SORGHUM (Sorghum bicolor) [1/]

Although sorghum grown as a food crop appears to have originated in Eastern Africa (Ethiopia and Sudan), it was extensively grown throughout Africa from earliest historical times and has been widely adopted in the Americas and Asia as well as in the Mediterranean and Near East regions. It is the fifth most important cereal grain in the world, outdistanced only by rice, maize, wheat and barley. However, it is still a relatively undeveloped crop from the standpoint of benefiting from modern science and technology. It offers much promise of increased productivity in the hands of cultivators, as present knowledge and improved types are more widely disseminated. The following sections deal with the practical aspects of production in tropical and subtropical regions, and the apparent opportunities for improvement. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) at Hyderabad, India has included sorghum as one of its four major crops for which it will be primarily responsible for worldwide research and training support. The other cereal is millet.

Sorghum Grain As A Food

Sorghum grain is primarily an energy foodstuff, since the major food constituent is starch (70%). The crude protein content averages about 9%, and oil content 3.5% but there is a great range among varieties. As a major food in the diet, it should be supplemented with high-protein foods, such as animal products, food grain legumes, and oil seed meals. Sorghum protein is deficient in two essential amino acids - lysine and methionine. Although maize is somewhat higher than sorghum grain in total nutritive content, the custom of home processing maize in certain areas by the wet method that loses much of the protein makes this maize less nutritious than whole grain sorghum home-milled for food. There are wide differences in food flavor for the various grain types of sorghum. In general, the white seeded types are preferred for food. In two Ethiopian lines of sorghum Purdue University scientists have discovered a high lysine gene with Protein Efficiency Ratios (PER's) at least equal to that of opaque-2 maize.

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Adaptation

In general, sorghums are the preferred cereal food grain where the climate is too dry for reliable maize production. Sorghum tolerates poorly drained soils better than maize also. Sorghum tolerates short droughts, even when so severe as to blast the heads during their development, with recovery if rains permit renewed growth. If the entire head is severely damaged, the plant produces new tillers that develop heads with normal grain. Short droughts at other stages are tolerated by temporary rolling of leaves that reduces water loss from the plant. However, sorghum yields are greatest when no droughts occur during the growing season.

Sorghum also is adapted to regions of limited rainfall by virtue of its well developed root system with abundant secondary roots that permit effective use of water held in the soil profile. Sorghum grows well on a wide variety of soils, from sandy to heavy textures where drainage is good and naturally fertile. Sorghum also is quite tolerant of saline and alkali soils that are widely prevalent in regions of limited rainfall. Its adaptation to relatively dry climates and its resistance to some important pests that plague maize make it an attractive food crop. Sorghum has not yet received as much attention by plant breeders to develop improved types as has maize, but outstandingly productive varieties and single-cross hybrids are now available. Bird damage to field grain in the head can cause very serious losses. The devastations by certain insects on sorghum are problems that have received some attention but are still locally serious.

Sorghums grown for food grain have a dominant position in all tropical and subtropical regions with limited rainfall. Since there are varieties with short, medium and longer growing season requirements, the choice of varieties that will grow and mature during shorter or longer rainy periods permits the crop to be grown successfully over a very wide range of climatic conditions, from a minimum of 3 to 4 months when moisture is adequate, to 6 to 8 months with recurring rains. Sorghum is a warm weather plant, and its culture in the subtropics is limited to the warm seasons. Sorghum is grown at high altitudes in Uganda and Ethiopia, but improved varieties specifically adapted to the cooler conditions have yet to be developed.

Plant Characteristics

Sorghum belongs to the grass family, and its plant and seed characteristics show that relationship. It is a coarse grass, with stalks of 1 meter to 5 meters in height (depending on variety); the stalks are made up of 15 to 30 joints, with a leaf developed at each node of the stem. There may be a few to many tillers arising from the plant base, depending on variety, favorable growth conditions, and density of plants stands. Each tiller developes its own root system, which must compete with its neighbors for moisture and soil nutrients. All stalks produce a terminal head, which has shorter or longer branches, with complete flowers at the ends of the branches. Both stamens (male) and pistils (female) are borne in the same floret. Self pollination occurs normally (an average of 95% with a range of 50 to 100%). Male sterility is used in the production of hybrid seed and wind pollination gives good seed set on the female male-sterile line. Regional races or types have come to predominate in most sorghum growing regions as a result of continued mass selection by man and natural selection by nature through environmental effects.

Types of Sorghum

From the standpoint of plant type and usage of the crop, it is convenient to recognize three main types: (1) grain types in which the seed threshes clean of glumes, (2) sorgo types in which seed is completely enclosed by glumes when threshed, and (3) grassy types, as typified by the wild types. Within this grain production group there are numerous head and kernel differences, and Harlan has used these to describe five important races; Bicolor, Guinea, Caudatum, Kafir, and Durra. The grain types in general have larger heads and produce more grain in proportion to the vegetative part of the plant, than do the sorgo types that are grown primarily for syrup. The sorgo types have abundant sweet juice in the stalks, but the grain sorghum types have stalks at maturity with either a dry or slightly sweet pith. The sorgo types are palatable feed for ruminant livestock, as well as being suited for making syrup; whereas the stalks of grain sorgo are less palatable and nutritious for livestock feed.

Seed Types

The grain types of sorghum not only are variable in plant characters but also in seeds. The seeds of individual varieties may be pink, red, brownish, yellow or white. The texture may be chalky or flinty, The seed shape may vary from roundish ovoid, to flat. Head shape and size also vary widely. Shallu and kaoliang have loose heads (panicles), with grain borne at ends of slender branches, reputed to reduce bird damage since it is more difficult for birds to perch on the branches and eat the grain. Unfortunately this type of head does not contribute significantly to protection from bird damage. Shallu is a preferred type in India, Egypt and Sudan, but kaoliang is almost exclusively grown in China, Manchuria, Korea, Japan and Siberia.

White or yellow seed grain types are generally preferred for food, since the pigmentation (red, pink, brown) makes the grain slightly bitter. The pigmentation is largely in the outer layers of the seed coat, and this may be removed by a limited amount of milling. If the pigmentation is in the testa, removal by milling is not practical by current machinery. The tannin compounds in the pigments reduce protein digestibility.

Sorghum Improvement

In those regions of the tropics where sorghum breeding has been undertaken, substantial improvements in productivity, and in plant and seed types have been achieved. Local testing of pure seed lots of improved strains and varieties is necessary to evaluate the productivity and grain quality produced by breeders elsewhere.

The first step in sorghum improvement is to make comparative field trials of all available varieties and strains that have shown promise within the region, or at other research stations in similar ecological regions. These should be grown in field trials designed to give all seed lots an equal opportunity, with cultural practices that permit relative productivity in response to favorable growing conditions. The results of a single field trial are not reliable and results must be obtained from several trials under representative environmental conditions. Pure seed must be used in each trial. When a superior variety or strain has been identified, production of high quality seed must be undertaken. This production should be identified as pure seed of an improved variety or strain, by some system of monitoring seed production and certification by an official agency. Farmers can be encouraged to produce their own seed of the improved variety since sorghum is normally self-pollinated. Sorghum seed is subject to rapid loss of germinating ability unless well dried at harvest time, and stored in a thoroughly dry condition. In general, the exploitation of improved sorghum requires the development of a well regulated seed industry, to facilitate the distribution of improved varieties as they become available from breeding programs.

Breeding populations have been formed from a wide range of adapted varieties with the genetic male-sterility factor in Uganda, Nigeria, and India. These populations are being selected for disease and insect resistance, improved protein quality, and higher yields. Improved varieties and hybrids can then be extracted periodically from the improved populations for release as commercial varieties. The cytoplasmic male sterile-genetic restorer system is used in production of single-cross hybrids.

The length of the growing season in the sorghum growing areas is usually determined by the rainfall distribution. Since maximum yields will not be obtained unless the variety has the correct maturity, the breeder must develop the varieties to meet the maturity requirement. The rainfall season and temperatures (as determined by altitudes and other factors) during the growing season may reduce the range of adaptation or sorghum varieties and require varieties for each ecological area or zone.

Culture of Sorghum

Sorghum should be planted in a mellow seedbed, preferably when the soil is moist to stimulate rapid germination. The seed is small (45 to 60 per gram), and relatively shallow planting (approximately 1.5 - 2.0 cm), is desirable to permit sprouts to push through the soil. The danger of soil crusting to impede seedling emergence is greater with heavier soil texture, particularly when intense rains occur, followed by rapid drying. Sorghum should be planted in rows 60 to 100 centimeters apart, and may be drilled within the row or planted in hills 20 to 50 centimeters apart within the row. The rate of planting should be based on average rainfall distribution, water holding capacity of the soil, and moisture and light requirements of the variety. Under optimum growing conditions, drilling the seed in narrow rows will produce higher yields than hill planting. Seeding rates are generally 1 kg/ha in very dry areas, 2-4 kg in more favored areas and 4-6 kg or more for irrigated sorghum when moisture supply and a mellow soil permits prompt germination. Seedlings should emerge in 3 to 5 days under favorable conditions; but may take longer if soil moisture is low, or when soils are cool (at high altitudes or in subtropical zones).

In a grain sorghum yielding 50-60 q/ha, the total uptake of N, P_2O_5, and K_2O has been found to be 130-180, 50-65, and 100-130 kg/ha, respectively. As with maize the amount of fertilizer to be applied should be determined by the attainable yield level and the level of available nutrients in the soil. Under irrigation, or when rainfall is reasonably abundant, good responses have been obtained from as much as 100 kg/ha of fertilizer nitrogen. Except in regions of heavy rainfall, the nitrogen ferrilizer may be applied prior to planting. With heavy rainfall, the nitrogen fertilizer may be applied prior to planting. With heavy rainfall, the possibility of severe leaching of nitrogen through the soil increases, and it may be advantageous to apply half of the fertilizer before planting, and the remainder by broadcasting just before plants produce heads. In regions where moisture supply is occasionally a limiting factor, lesser amounts of fertilizer are more economical; and under some conditions, there may be no nitrogen response. The economic rates of fertilization should be determined by field trials.

Phosphate fertilizers should be added if the soil is deficient in phosphorus and to prevent soil fertility depletion under continued cropping. Up to 50 kg per hectare of phosphate (P_2O_5) is suggested as being economic, but actual field trials should be conducted to establish levels of profitable phosphate applications under local conditions. Phosphates are most effective when applied below and to one side of the seed.

Sorghums have been credited with being exhaustive of soil fertility; with succeeding crops of other types being reduced in yield when they follow sorghum. There is experimental evidence that reductions in soil fertility following sorghums may be caused by (1) a decrease in soil nitrogen caused by higher rates of decomposition of sorghum stubble, stalks, and roots; this decomposition being temporarily accelerated because of the higher content of soluble carbohydrates in the plant residues; and (2) the temporary reduction in soil moisture caused by the extensive root system of sorghum. The first factor is compensated for by addition of nitrogen fertilizers, which nitrogen is not lost, but becomes available to subsequent crops; and the second factor by soil management to recharge moisture in the soil profile through weed control and by practices to reduce rainfall runoff. The rewards in terms of higher sorghum yields with effective cultural practices more than offset the costs of the residual effects of growing the crop. The use of sufficient nitrogen fertilizer (or of applications of dung, or of leguminous green manures) and of rainfall conservation are necessary integral factors of increased production of most other crops, as well as sorghum.

Weed Control

Witchweed

The most devasting weed affecting sorghum is witchweed. There are two species *Striga hermonthica* and *S. asiatica*. This is a parasitical seed plant that attaches itself to the roots of the host crop plant and makes its own growth by absorbing moisture and plant juices from the host roots. The parasite appears above ground 3 to 6 weeks after it has infected the crop roots, and then develops green leaves, flowers, and produces seed. Witchweed seeds abundantly, and the seed may remain dormant in the soil for extended periods, up to several years. The infected host plants may be reduced in growth by 50%, when heavily infested.

A control measure that has some value is growing a legume, cotton or other immune crop in rotation with susceptible cereal grains. The witchweed cannot parasitize the pulses, groundnuts, soybeans, and cotton; and these crops reduce the abundance of the witchweed so that a grain crop may follow. A companion, or separate treatment, is to treat the sorghum fields with herbicides of the 2, 4-D or MCPA types; however the witchweed can not be killed until it starts to emerge which is after it has parasitized the crop. These treatments do not eradicate the witchweed, but reduce its damage in most cases. Research is underway at some stations on propagating certain diseases of witchweed and fostering various insect pests of the weed as well as to select varieties with greater tolerance. Until this research produces results, reliance must be placed on use of selective herbicides, and growing susceptible crops in rotation with immune crops.

Other Weeds

Perennial weeds are best controlled by tillage in preparation for planting. Annual weeds should be suppressed by hand pulling, hoeing, or cultivating, or by application of herbicides. These various methods are effective only to the extent that the weeds are killed early, before they damage the sorghum plants by competition for soil nutrients and soil moisture. Damage to the sorghum plant roots from weed competition may be halted but not corrected when larger weeds are killed. If removal of the weeds damages the crop root system, crop yields will be severely affected. This is particularly true if weed removal is followed by shortage of soil moisture that prevents regeneration of the damaged crop root system.

Weed removal by application of appropriate herbicides is rapid and avoids physical damage to the crop root system; but the cost is substantial and each herbicide must be used as prescribed by the manufacturer. Different species of weeds require different herbicides, and some of these herbicides leave a residual toxicity in the soil that affects other succeeding crops. As in the case of physical removal of weeds, early treatments generally produce the greatest benefits in crop yields.

Insect Pest Control

The sorghum shoot fly attacks sorghum in the early stages of crop growth, often when the plants are 2 to 5 cm high. The adult fly lays eggs on the underside of young leaves and the developing larvae enter the funnel and move down to feed on the meristem. The central shoots become yellow and then die; affected plants often compensate for this damage by producing several tillers but these may also be attacked. There is resistance to shoot fly in some varieties; this depends on the ability of the plants to produce new and vigorous tillers which rapidly grow beyond the stage at which they can be attacked. Early planting is important; late planted crops are often devasted by this pest.

Borers of many types occur; most of these being the larvae of moths. Their control is facilitated by plant sanitation, i.e., the removal of all crop residues through consumption by livestock, or plowing under to kill the dormant forms of the insects. Chemical control can be very effective on some types. Predators and parasites of the several borers are being sought, and will doubtless be useful. The varieties or strains of sorghum that are resistant should be identified and used.

The sorghum midge attacks the panicle and prevents seed from developing; at present tolerance to the midge is being incorporated into commercially grown types. Chemical control is effective but too costly to be practical except in extreme cases. The development of parasites offers promise and is being pursued by researchers.

Chinch bugs which are sap sucking insects, may be serious pests on growing sorghum plants; but resistant varieties and strains are now available. Another type of sucking insects - aphids - may become quite serious on the "head" or panicle. Resistant varieties are effective in controlling aphid damage.

Wireworms may severely damage planted seed before it germinates and emerges, but may be controlled by seed treatment with aldrin or dieldrin before planting. This is compatible with seed treatments for disease control.

Control of Sorghum Diseases

There are numerous molds (fungi) that may attack planted seeds when soil temperatures are below 20°C, particularly with sorghum types that have soft mealy grain. Fortunately, these diseases are least troublesome when prompt germination occurs in warm, moist soils. Chemical treatment of seed with thiram before planting is recommended, since it is effective and not poisonous. Instructions on the container should be followed.

Fungal leaf diseases includes leaf spots, downy mildew, rust, anthracnose, and blights. In most cases there are strains or varieties that are resistant to individual diseases; and such improved types should be selected that are resistant to the diseases that are locally important. It is generally found that such diseases are more abundant on sorghum grown in humid climates or in rainy periods. This is one of the reasons for selecting sorghum as a grain crop for regions of limited rainfall, where humidity of the air is characteristically low.

Red rot and charcoal rot are fungal diseases attacking the sorghum stem and root. Some varieties are much more susceptible than others, and resistant types should be grown. However, these diseases tend to build up in the soil, and crop rotation tends to reduce these problems.

Ergot, covered smut, loose smut, and head smut and long smut of the heads may cause substantial losses. Fortunately, there is good resistance among sorghum strains to these diseases, and resistant strains should be grown. Crop rotation is useful in keeping these diseases at low levels. Fungicidal seed treatment gives excellent control of covered smut.

For further information on Crop Protection, see Chapter 4 in book on "Tropical Agriculture" by Wrigley, (Reference list following Chapter 40).

Bird Damage and Control Measures

Sorghum grain is a preferred food of many birds, including the Quelea bird, sparrows, yellow weavers, bishop birds, doves, parrots, crows, and buntings. Fortunately, the type of bird pest varies with the regions, but collectively, bird losses have a profound effect on choice of a grain crop. There is a tendency to substitute maize for sorghum in regions where sorghum actually is much better adapted to the climate and soil and produces more grain, because maize is less susceptible to bird damage by reason of the husks that tightly enclose the ear.

The Quelea bird is the most damaging of all bird pests. They feed in swarms and will rapidly strip a field when they invade it. Present research is directed toward reducing total population of Quelea birds to a tolerable level, and to prevent them from building up again. The areas affected by these scourges are identified, and sorghum is not a preferred crop in these areas.

Elsewhere, birds are problems for which some control is possible. The factors affecting attractiveness of the grain are taste, size, and hardness of grain. The plant breeders are undertaking to develop resistant types. The milling of types that are not attractive to birds to remove the bitter outer layers may be useful. However, birds remain as a serious deterrent to sorghum production.

Sorghum Harvest

Sorghum grains are fully developed when they reach the "dough" stage and the black layer forms where the seed attaches to the pedical; thereafter the ripening process consists of gradual loss of moisture. This drying proceeds most satisfactorily in the field, unless bird damage is a serious risk. Varieties differ in the time to reach maturity, from 4 to 6 months from planting date. The bird problem is most serious during the milk, dough, and mature stages of the grain, and any campaign to repel birds should be concentrated in these stages. Early harvest of heads as soon as the grain reaches black layer is advisable when bird damage threatens to be serious.

Completion of drying of harvested heads should be accelerated by spreading in a loose layer on a hard surface for sun-drying. Moisture content should be reduced to about 10% (from 20 - 25% when field harvested) to avoid molding. Threshing may occur as soon as the grain is dry. Sorghum appears more susceptible to molding than other cereals, particularly the types with soft, chalky grains.

Storage

Sorghum grain should be completely dry when placed in storage. Initial treatment to give protection against storage insects is universally important, since sorghum grain seems to be quite susceptible to insect damage. The more serious insect pests of stored sorghum grain include the rice weevil, lesser grain borer, khapra beetle, other grain beetles, and the larvae of the grain moth. The control of these stored-grain pests is reviewed in more detail in the Chapter on Maize, section on "pests of stored grain". Malathion is effective in treating empty storage containers and structures. Grain is best protected by fumigation at time of storage, repeated if necessary during the storage period.

CHAPTER 8

MILLETS [1/]

The millets are warm-weather annual grasses or cereals grown for their edible seeds. The more important species are:

Major food species

1. Bulrush millet - Pennisetum typhoides
2. Finger millet - Eleusine coracana

Lesser food species

3. Foxtail millet - Setaria italica
4. Proso millet - Panicum miliaceum
5. Japanese millet - Echinochloa crusgalli var. frumentacea
6. Browntop millet - Panicum ramosum

In general, the millets are most useful where a grain crop is needed to capitalize on short-growing periods. This role is most important in the dry tropics where the period having adequate rainfall for crop growth is short -- 3 to 5 months; or in regions of more adequate rainfall where a short-season grain crop can be grown as a secondary planting following a main crop on the same land. In regions of severely limited rainfall, millet may be the principal cereal because of its flexibility in management to avoid droughts.

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) has been established at Hyderabad, India to provide worldwide research and training support on this crop. Of those grown primarily for food, finger millet and pearl millet are considered the most important types.

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Millets as Foodstuffs

Millets are used as a meal for making flat bread and cakes, or as paste from pounded soaked seed, or as boiled gruel. Millets may also be used in making beer and other alcoholic drinks. Millet grains are high in starchy components, 55 to 65%, and thus serve as energy foods. The protein content and quality differ greatly among types, but they are deficient in the nutritionally essential amino acid lysine, in common with other cereal grains. However, the seeds are usually small, and the germ (which is richer in protein) is not separated from the rest of the seed, so that the full dietary value is retained in food made from the millets. The seeds of bulrush millet are larger than the other millets.

Regional Production

Bulrush millet has the greatest use in Africa and India and finger millet in India, Pakistan and parts of East and Central Africa. Total production of millets in Asia and Africa is somewhat smaller than for sorghum, but in some subhumid environments the millets are the dominant cereals.

Bulrush Millet

Other common names are cattail millet and pearl millet. This millet is usually a short-season crop, often grown in rainfall zones of less than 600 mm yearly, during the short periods when soil moisture will sustain crop growth. It does best where light showers followed by bright sunshine prevail during the growing period. It is somewhat drought resistant by virtue of its well developed root system and hairy stalks and leaves. Also, it is tolerant of rather infertile soils as well as sandy soils. Protein is usually of good quality and quantity, although a somewhat higher content of lysine would be desirable.

Description

It is an erect grass plant with strong round stalks, 2 to 3 cm thick, growing to a height of 1¼ to 3 meters. The leaves are 5 to 7 cm wide and reach lengths of 1 meter or more. It has a stiff cylindrical head, 20 to 40 cm long and 2.5 cm in diameter. The grains are borne in fasicles with short attachments to the central stem of the head, with exposed yellowish gray to whitish naked seeds. The seeds are 3 to 4 mm long and 2¼ mm wide, the largest of any of the millets. Bulrush millet flowers are cross pollinated by wind, and this habit dictates the techniques of breeding for crop improvement.

Bulrush Millet Improvement

Bulrush millet is normally cross pollinated, but it can be easily selfed. The cytoplasm-male-sterility-genetic-restorer system has been identified and used successfully for single-cross hybrid production in the United States and India. The World Collection of bulrush millet has been evaluated and selected collections and varieties have been used as source material to develop breeding populations in Uganda, Nigeria, Senegal and India. These populations are in selection programs to improve the yields, lodging resistance and disease resistance. These populations are available for use as synthetic varieties or as sources of inbred lines for hybrids.

Culture

The seedbed for millet should be prepared in anticipation of prompt planting when soil moisture becomes adequate. Since the seed is small and must be planted shallow, the seedbed should be mellow. The crop responds to complete fertilizers (nitrogen, phosphates and potash) where soil moisture is adequate, and to liberal applications of animal manures. It should not be assumed that limited rainfall prevents response to improved fertility, but local field tests are needed to determine the amounts of fertilizer or manure that will be profitable.

The crop is usually planted by hand in hills spaced 50 cm apart, in rows 1 meter apart. Several seeds are dropped per hill, to assure at least one plant each. When improved cultural practices are used, higher yield can be obtained from drilling in narrow rows. The growing period to maturity is 4 to 5 months for most types. The plant density should be determined according to expected available moisture.

Weed control is quite important, since any weed growth exhausts soil moisture and competes with the millet for soil nutrients. All weeds should be removed while still small in order to avoid damage to the millet root system.

When the grain is mature, the heads are cut by hand, and when dry the grain flailed out on a threshing floor. If bird damage threatens, the heads may be harvested when seeds reach the hard dough stage, and drying completed by sundrying on hard surfaces to about 10% moisture content.

Bulrush millet may suffer severe damage in storage, from grain infesting insects, unless specific precautions are taken. Protection must begin with treatment of empty storage structures and containers, using malathion to kill insects hiding in cracks and crevices. Grain should be fumigated when placed in storage.

Downy mildew, rust and ergot sometimes cause a reduction in yield. Effort is currently underway to breed varieties resistant to these diseases.

Finger Millet

Other common names are ragi, birdfoot millet, coracana millet, and African millet.

Regional Use

Although the greatest use of this millet is made in India and Pakistan, it is also grown in many parts of East Africa as a short-season grain crop. It fills a niche in the ecological environment somewhat different than bulrush millet. Finger millet thrives in a moist climate but not where there are continuing heavy rains. Also, it grows at altitudes of 2,000 to 2,500 meters, on rocky and shallow soils where moisture supply is abundant. The highlands of Ethiopia, Somaliland and Sudan provide favorable conditions. On the Indian subcontinent, it is grown extensively in the Himalayan foothills, and also as a second crop on lowlands cropped yearly to rice.

The food uses of finger millet are similar to those described for bulrush millet. Protein content is generally low. Lysine is deficient but methionine is high.

Description

Finger millet is an annual crop that grows to 1 to 1-1/3 meters in height, producing a terminal inflorescence, containing small round brownish-red grain. The plants have a capacity to tiller and branch freely. The inflorescence is borne on a long stem from which 4 to 6 spikes radiate in a whorl - hence the name finger millet. The seeds are borne 1 to a floret, in clusters of florets, and thresh out naked at maturity.

Finger Millet Improvement

Finger millet is a completely self-pollinated crop and neither genetic or cytoplasmic sterility is available. The World Collection includes a large number of very diverse varieties that can be evaluated for improved varieties for commercial use. Selected varieties have been manually intercrossed at the Serere Research Station in Uganda to develop a breeding population. New varieties have been developed that are high yielding and resistant to lodging and a head blast disease.

Culture

Finger millet is best planted on a clean, mellow seedbed. The crop responds strongly to fertilizers and/or animal manures. Fertilizers supplying both nitrogen and phosphate are preferred, at the ratio of 2 to 1. Care should be exercised in applying nitrogen as in excess it induces lodging.

Unlike bulrush millet, finger millet is either sown broadcast at the rate of 20 to 30 kg/ha, or in closely spaced rows 20 to 30 cm apart at a reduced seeding rate. In regions where the crop is planted in wider rows of 40 to 60 cm spacing, the seeding rate is reduced to 10 to 12 kg/ha. The seed is small and must be planted shallow, 1 to 2 cm deep to insure emergence of seedlings. Germination is 5 to 10 days, being longer in cooler weather.

Weed control may be a serious problem in finger millet. For this reason, special attention is often given to several successive cultivations at 7- to 10-day intervals during seedbed preparation, to germinate weed seeds and kill seedlings before the crop is planted. Because of the difficulty of hand pulling or hoeing weeds in thickly planted finger millet fields, it is probable that the use of appropriate herbicides, such as 2, 4-D to control broad-leafed weeds, would be practical. Tests of other herbicides to control grassy weeds are needed; these must be herbicides that will not injure the finger millet.

The principal diseases are caused by a fungus that causes root rot, leaf spotting and headblast, and a grain smut. These diseases are most prevalent when the land is cropped yearly to finger millet. To curtail a build-up of disease inoculum, finger millet should not be grown on the same land in successive years.

Harvest

Finger millet matures in 3 to 5 months. The mature plants are customarily cut close to the ground, tied into sheaves and stacked to dry. The grain is threshed out by beating the sheaves, or by mechanical means. In the case of irrigated finger millet, the heads do not all ripen simultaneously. The individual heads are harvested as they ripen, spread out on a drying floor for a few days to cure, and then threshed in the usual manner. Good grain yields under natural rainfall may reach 2,000 to 4,000 kg/ha; irrigated crops may yield somewhat more.

Control of storage insects in finger millet is less of a problem than for bulrush millet because of the small seed size. The treatments suggested for bulrush millet are applicable to finger millet.

Lesser Millets

The lesser millets are of importance in certain localities. Proso (broomcorn millet) and foxtail millet (Italian millet) resemble bulrush millet in their ecological adaptation to climate and soil, and constitute "catch crops" that will produce a grain crop in 60 to 90 days. This makes them useful in regions of limited or uncertain rainfall. These millets may be grown in rows to permit cultivation, or planted broadcast. Their utilization as food crops resembles bulrush millet.

Japanese millet and browntop millet more nearly resemble finger millet in their climatic adaptation and in their responses to rather high levels of soil fertility. Cultural practices for finger millet are generally applicable to these two millets.

CHAPTER 9

WHEAT 1/

(*Triticum aestivum* - bread wheat)
(*Triticum turgidum* - durum wheat)

Wheat is of two major genetic groups; the durum wheats with 14 pairs of chromosomes, and the bread wheats with 21 pairs of chromosomes. All wheats are self-pollinated, and any natural hybridization is relatively rare. Even with man's intervention, it is difficult to "cross" durum and bread wheats.

Durum wheats generally have hard kernel texture. They are used to produce macaroni and similar pasta products, rather than bread. Bread wheat varieties may have either hard or soft kernel texture and contain substantial amounts of gluten (a proteinaceous substance) that imparts the cellular structure to leavened dough when it "rises" under controlled fermentation, and it is baked into bread, rolls and similar products. Bread wheat is the only cereal grain that contains gluten of a quality capable of producing leavened bread.

These two wheat groups have had separate geographic origins in their evolution. The durum group is believed to have originated in the Ethiopian region and spread from there in early times to North Africa and the Mediterranean Region. The bread wheats are believed to have originated in the Near East in the areas now occupied by Syria, Turkey, Afghanistan, Iraq and Iran. The bread wheats early spread to the European Continent, and were introduced into other continents by early explorers and colonists. Durum wheat was introduced into North America in the Great Plains area in recent historic times, and now comprises 1/16 of the USA acreage. They are used extensively in North Africa and the Mediterranean Region.

Except where durum wheat is specifically mentioned in the following discussion, the information applies to the bread wheats and may or may not apply to durum.

Wheat is a cool season crop. The greatest world production occurs in the temperate zones, but because it is grown at higher altitudes in the tropics and subtropics, it occupies an important position as a foodstuff in these

1/ Edited by Louis P. Reitz, Staff Scientist (Cereals), National Program Staff, Agricultural Research Service, U.S. Department of Agriculture, Beltsville, Maryland 20705 and John G. Moseman, Chairman, Plant Genetics and Germplasm Institute, Agricultural Research Service, U.S. Department of Agriculture, Beltsville, Maryland 20705 regions. The dwarf, stiff-strawed, high-yielding spring wheats that are an important component of the "Green Revolution" were bred in Mexico utilizing high altitude locations for a summer crop and low altitude locations in Northwestern Mexico for a winter crop. They have had a great impact on the agriculture of India, Pakistan, Afghanistan, Iran, Turkey, and Tunisia; and the lessons learned in these countries are being applied to other regions. Wheat growing is important in North and South Africa, at higher altitudes in East African countries, and in Argentina and the Andean countries of Colombia, Bolivia, Peru and Chile. The durum wheats have not spread much beyond North Africa, but the bread wheats predominate in all wheat growing regions of the tropics and subtropics. The bread wheats are in great demand because of the many kinds of leavened bakery products made from bread wheat flour, and the prompt acceptance of such foods wherever available.

The bread wheats include two types of growth habits - (1) the <u>spring annuals</u> planted at the beginning of a growing season, that do not require exposure to low temperatures to stimulate head formation; and (2) the <u>winter annual</u> type that does require exposure to low temperature to complete the normal growth cycle. The high-yielding Mexican-type or semi-dwarf wheat varieties are spring annual types, and they will not survive long exposure to temperatures several degrees below freezing that occur at higher altitudes, such as those prevailing in regions extending from Turkey to India. The spring annual types grow very well in these regions when planted after freezing periods have passed. In general, these spring annual types are adaptable to the tropics and subtropics.

<u>Wheat as a Foodstuff</u>

Wheat is rich in carbohydrates (about 70%) and is primarily an energy food. The crude protein content ranges from 8 to 15% depending on type and variety; it is highly digestible, but deficient in several nutritionally essential amino acids, primarily <u>lysine</u>. In milling wheat for flour, the pericarp and germ are removed from the grain, and since much of the protein and fats are in these portions the resulting flour has nutritional values lower than the whole grain. However, the gluten retained in the flour is sufficient to make bakery products of the desired palatability. Intensive research is now under way to increase the amount and to improve the quality of protein of wheat, to make it more nearly a complete food.

Description

Wheat is an annual grass that normally produces 2 or 3 tillers per plant under crowded field conditions, with a spike (head) at the top of each tiller. The stems are jointed and hollow, with a leaf produced from each stem joint. The spike averages 15 to 18 spikelets, each containing 2 or 3 grains. The root system is fibrous, produced mostly by adventitious roots developed at the stem nodes of each stalk or tiller just below the ground level. The root system may permeate the soil to depths of about 1 to 2 meters, if soil conditions are favorable.

Wheat is largely self-pollinated, since pollination normally occurs before the florets open. Varieties "breed true" to type, permitting growers to save their own seed without deterioration in hereditary vigor. Breeding programs to improve yields and quality of grain are being aggressively pursued in many countries.

Adaptation

Wheat prefers a comparatively cool growing period with moderate rainfall; but yields are not reduced by comparatively high temperatures during the last few weeks before harvest, provided the soil moisture supply is sufficient to meet plant needs. Irrigation to supplement natural rainfall may be required to supply the necessary moisture during the grain formation period of about 30 days after pollination. High humidity during the vegetative period favors the development of diseases of leaf, stalk and spike. Excessive moisture supply also tends to produce tall, weak stalks, that are easily lodged in storms with resulting severe reduction in yields. Semidwarf Mexican-type wheats are lodge-resistant because of the short, stiff-straw, and are nonsensitive to day length. These characteristics widen their ecological adaptation, and permit heavier fertilization for much higher yields.

Wheat prefers loam to clay loam soils that are fairly deep and well drained, with moderate to high soil fertility. Deep soils have the capacity to store ample soil moisture, which the wheat plant utilizes for sustained growth even though rains are intermittent. Sunny weather favors high yields, so that the highest wheat yields are achieved on deep, fertile soils in regions where there is ample sunshine.

Fertilizers

Prior to the development of semidwarf wheats it was believed that wheat would not tolerate heavy fertilization without causing severe lodging and greatly reduced yields. Heavy applications of manures were as undesirable as heavy usage of nitrogen fertilizers. This belief was disproven when the short, stiff-stalked wheat varieties were bred; these varieties did not lodge under higher levels of fertility. It was then possible to breed for higher capability in yielding power, with greater amounts of fertilizers and abundant moisture under irrigation, and to combine these traits with resistance to wheat diseases. This research lifted potential yields to as much as 4- and 5-fold yield increases over indigenous wheat production. Many tropical and subtropical countries have now benefited from the introduction and further improvement of this type of wheat. However, it is abundantly clear that improved cultural practices must accompany the use of these productive wheat varieties to achieve high yields. Under practical farm conditions, even where cultural practices have not been completely controlled, national wheat yields in such countries as India and Pakistan have increased 25% following adoption of these wheats and the improved practices for growing them on a large scale. These wheats are grown primarily under irrigation (which is often faulty), but certain improved varieties may also have substantial value under natural rainfall where moisture conservation practices are followed such as has been demonstrated in Tunisia.

Breeding

Breeding programs are underway to expand the value of semidwarf wheats by developing improved resistance to the diseases and insects prevalent in different regions, without loss of the short, stiff-stalked trait and high yielding power. Also improved winter wheat types are being sought that would be more useful in North Africa and the winter wheat regions extending from Turkey to India. In addition, serious research programs are underway to improve the nutritive quality of the wheat proteins.

Varieties

Wheat breeding programs, in many wheat growing regions, have developed improved varieties of both spring and winter types of wheat. Many of these have already been proven to be significantly superior to the wheat varieties commonly grown in the tropical and subtropical wheat-growing regions. The wide adaptation of day-length insensitive spring wheats permits extensive sharing of the plant breeders product.

Field trials of promising new wheat varieties should be made in representative locations to determine their immediate value, and the most promising should be made available to farmers along with a "package" of cultural practices suited to the locality. Since these wheat types will "breed true", improved varieties may be rapidly multiplied, and growers, by avoiding mixture with common seed in harvesting and threshing, may save their own seed without loss in heritable traits. A precaution is that improved varieties must be accompanied by effective cultural practices to produce increased yields.

Culture

The wheat seedbed should be free of weeds, well supplied with moisture and rather compact to permit prompt germination. The soil fertility should be assured by incorporation of animal manures and/or fertilizers containing nitrogen and phosphate generally at a ratio of 2 to 1. The amounts must be adjusted to the inherent soil fertility, and the probable supply of soil moisture, as determined by local field trials. However, it is a mistake to assume that fertilizers are not useful in less humid regions, since increases in nitrogen and phosphate may stimulate root development so as to exploit deeper soil moisture reserves. Wheat grown under natural rainfall will benefit greatly from soil conservation and tillage practices that retain rainfall in the profile rather than permitting its loss as runoff. With limited rainfall, water conservation has paramount importance, and the soil moisture status at planting time is an important factor.

Planting of spring wheat should take place as soon as danger of killing freezes has passed. For winter wheat, planting should occur at least 6 weeks before low temperatures slow growth, so as to develop a substantial root system for the over-wintering period. Wheat is usually planted in rows 15 to 20 cm apart, with at least one plant per 5 to 10 cm of row. Drilling of seed about 3 to 5 cm deep places the seed in moist soil (or soil that will stay moist after a rain) for prompt germination. Such machine planting is far more certain to produce a full stand of plants than broadcasting, although broadcasting is successful when frequent showers can be expected after planting. Eighty kilograms of seed should plant 1 hectare when drilled in rows, and up to 120 kg of seed may be needed for broadcast sowings.

Weed control, after sowing, is usually not required or practical but may be necessary on heavily infested land. Removal of weeds by pulling or tillage usually severely damages the wheat root system; solid planting of wheat on a weed-free seedbed is usually relied on to provide enough competition to reduce weed damage to the wheat crop. Weed removal on irrigated wheat is less serious than on rainfed crops, because wheat will regenerate damaged roots if moisture supply is adequate, particularly at early growth stages. Weed control by use of appropriate herbicides to combat the important weed species at hand becomes a useful treatment on heavily weed infested fields. The wheat root system is not damaged when the herbicides are properly used.

For further information on Crop Protection, see Chapter 4 of book on "Tropical Agriculture" by Wrigley. (See Reference list following Chapter 40.)

Harvest

The wheat crop usually ripens about 30 days after blooming of the florets. The kernels are completely filled when they reach the dough stage, at which time the leaves, stalks and spikes begin to lose green color and become golden yellow. From this stage onward, ripening consists of gradual loss of moisture content of the kernels. When completely air-dry, the kernels will average about 10 to 12% moisture, at which time they may be stored safely without molding. Where bird or storm damage is threatened, the crop may be cut and bound into sheaves as soon as it yellows, and stacked in the field or in shelters to complete drying. Harvest may be done by hand with sickles, or with machines. Combined harvesting and threshing of standing grain by use of machines is practical in regions where the harvest period is dry, but the grain must be thoroughly dry before such harvest.

Storage

The first requirement for safe storage of wheat in the tropics is to have it dried to 10% moisture or less before placing it in storage. For higher moisture-content wheat, additional drying is needed to prevent spoilage. Protection of stored grain from storage insects is particularly important in the tropics and subtropics. It must begin with treatment of on-farm storage structures and containers to destroy insects hidden in these places, but initial fumigation of the grain as it enters storage is equally important. Some central storage agencies to which farmers make deliveries will not accept insect infested grain, or purchase it only at discount prices.

For further information on treatments to combat grain storage insects, see the Chapter on Maize, section on "pests of stored grain".

CHAPTER 10

BARLEY [1/]
(*Hordeum vulgare*)

Barley is an ancient food grain of Ethiopia, North Africa, particularly Libya and Morocco and to a lesser extent Tunisia and Algeria, and the Near Eastern regions. About 75% of the world production is in the temperate zones of North America and Europe where it is used as a feed for livestock and for brewing beer; but it remains an important food crop in the regions of its origin. It is also grown as a food crop in the Andean Countries of South American, especially Argentina and Peru, and in India, Turkey, Korea, Afghanistan, Iraq, Syria, Iran, and Pakistan. It is grown at higher altitudes of the tropics, and in irrigated areas of deserts that are too high in soil alkali for growing other cereals.

Types

Barley has many forms. There are winter annuals that require cool weather down to or below freezing during the seedling period to stimulate heading, and spring annuals that do not require cold exposure for normal development. Unlike wheat that threshes out naked kernels, barley is mostly of the "covered" type, in which the glumes adhere to the grain. However, the "naked" type is grown in the Himalayas and China. Individual spikelets may be awned, hooded, or awnless, and the spikes or heads may have two rows of kernels, or six rows.

Food Value

Barley is classed as a starchy food (65 to 68%) and is thus an energy source. Currently grown varieties average 12 to 14% protein; however, the protein is somewhat deficient in the nutritionally essential amino acids - lysine and threonine. It should be supplemented with protein foods in the human diet, particularly, animal products, foodgrain legumes, and oilseed meals. Barley is widely accepted as a palatable and nutritious food crop, despite the necessity of removing the hulls by abrasion in preparing it for food. The grain is normally prepared for food by boiling or parching the whole grain, grinding for making gruels, made into flour for baking flat breads, and used in other ways. Recent research findings in Sweden, Denmark, and at Montana State

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University indicate that it should be possible to breed improved commercial varieties with higher quantity and quality protein in barley.

Adaptation

Barley, with all of its forms, has a very wide ecological adaptation. Different varieties are used to produce crops in the cooler zones and in hot zones. However, barley is not grown in areas with high humidity and high temperatures. The best yields are obtained when there is a growing period of about 4 to 5 months, in which the vegetative period is relatively cool. It needs less moisture than wheat, but hot, dry winds after heading reduce grain yield. Shorter season varieties are used to escape drought damage in regions with short rainy seasons.

Winter-type barley varieties are grown in higher elevations where the cool season temperatures may fall below freezing, and spring-type varieties are grown in other regions with cool periods irrespective of the season. In North Africa and the Near East, spring barleys are grown wherever there are mild winters. For the colder environments, winter hardy varieties are available, however, none have been developed which equal wheat or rye in tolerance to low temperatures.

Barley is best adapted to well-drained, deep loam soils, and responds strongly to high fertility. Varieties are known which are relatively tolerant to the alkali soils which occur widely in all regions of limited rainfall. Shorter, stiff-strawed varieties are preferred for soils of higher fertility, to avoid lodging of the stalks before harvest. Barley does not tolerate imperfect soil drainage, nor strong soil acidity.

Description

Barley is a member of the grass family, with a fibrous root system, several tillers per plant, each having jointed hollow stems that carry a leaf at the stem node. The root system may extend a meter into deep, permeable soils, and utilize soil moisture to that depth. The terminal spike on each tiller has two or six rows of fertile florets borne sessile on the axis of the spike. There is one grain per floret, and the total number of grains per spike may vary from 20 to 60 or more, depending on variety and growing conditions. The grains in each spikelet, depending on variety, may carry fertile glumes with awns, hoods or be without them, and the glumes may range from straw colored to black. Most barleys grown in the tropics and subtropics thresh out with kernels covered by adherent glumes that must be removed by abrasion in preparation for human food. The barley kernel (within the glumes) may be creamy white, red, purple, blue or black, but white types are generally preferred. Most commercial barleys have awns that may be either sharply barbed or smooth. Many of the newly improved varieties have smooth awns which are not as objectionable to handle during harvest.

Barley begins flowering 2 to 4 months after planting, and the filling and ripening of the kernels requires about one month. Kernels are mature when they reach the dough stage of development, and th remainder of the ripening process consists of drying. Barley is ready for harvest and storage when the kernel moisture is reduced to about 12% or less.

Varieties

Several hundred improved barley varieties have been bred for temperate regions, and a small but substantial number have been bred and introduced for use under tropical and subtropical conditions. These varieties differ in length of growth period to maturity, stalk height, resistance to lodging, tolerance to soil alkali, responsiveness to soil fertility and fertilizers, and tolerance or resistance to plant diseases and insect pests. They should be evaluated for performance under local or regional climate and soil conditions and those that produce the highest grain yields under good cultural practices should be selected for further testing.

Since barley is a self-pollinated species, it breeds true to type in successive generations, and seed multiplication is easily handled. Farmers may save their own planting seed without loss of hereditary traits. They will profit from guidance on maintenance of purity and production, eliminating foreign matter and weed seeds, and on preserving viability.

Culture

Planting

Cultural practices for barley are similar to that of wheat and oats. All weed growth should be killed in preparation of a seedbed, and manures or fertilizer incorporated in the rooting zone below 3 cm. The seed should be planted by drilling to a depth of about 5 cm in rows 20 cm apart. Wherever rains are uncertain at planting time, hand planting in rows is acceptable, and is superior to broadcasting. Drilling seed in moist soil insures prompt germination and seedling establishment. For row planting, 80 kg of seed per hectare is sufficient; but for broadcast plantings the seed requirement should be increased to as much as 120 kg/ha. (NOTE: No recommendations are made on treating seed before planting, since such treatments are poisonous to man when surplus seed is eaten; and must follow in-country regulations.)

Weed Control

Barley is not cultivated for weed control, except on very weedy land where undue reliance must not be placed on competition from barley plants to subdue weeds. Handpulling of aggressive weeds is necessary on weedy fields, particularly where soil moisture may be a limiting factor in growth, since weeds quickly exhaust moisture supplies. Weed removal by pulling, hoeing, or by herbicide application should be done while weeds are small, before serious damage to barley plants has occurred. The herbicide selected should be one that experience has demonstrated to be effective in killing the weed species without injury to barley.

Disease Control

Several diseases are known to reduce the production of barley. Powdery mildew occurs wherever barley is grown and often causes large losses in production. Leaf rust is also important, but stem rust is not as important on barley as on wheat. In many areas, barley matures early and escapes from infection with the rust fungi. The disease, scald, occurs in the cooler climates. There are three smut diseases, which infect the spikes causing yield reductions, and viruses, which reduce plant vigor and winter survival. Leaf spotting and leaf blotching diseases are usually present on barley. The growing of resistant varieties is the most effective and economical method for controlling barley diseases. Selections or varieties are known which are resistant to these diseases. The use of disease free seed and cultural practices that assure vigorous plant growth will reduce losses. (Note: Fungicides are available for reducing losses from most of the barley diseases. No recommendations are made for using fungicide because such fungicides may be poisonous to man and their use must follow the in-country regulations.)

Insect Control

Several insects feed on barley. The greenbug aphid causes plants in small areas in fields to become stunted and nonproductive. Other aphids and leafhoppers are known to transmit virus diseases. There are varieties resistant to the greenbug and to most of the viruses transmitted by insects. The Hessian fly which infests fall-planted wheat also infests fall-planted barley. Losses from the Hessian fly can be avoided by delaying the planting until the weather is cooler. The cereal leaf beetle attacks barley in many countries in Southern Europe, North Africa, and in a few areas in North America. Sources of resistance to this insect have not yet been identified.

Harvest

The full yield of grain will have been achieved when the kernels have reached the dough stage, and the crop begins to turn from green to golden yellow. Full ripening occurs when the grain has dried to a moisture content of about 12%. Barley like wheat can suffer from bird damage, some varieties being more heavily attacked than others. Field curing is generally practical. Harvest may be by hand with sickles or by machines. Combined harvesting-threshing by machine is quite feasible with dry grain, but fairly large areas are needed to make this practice economically desirable, particularly where abundant hand labor is available.

Storage

Grain harvested with a moisture content of more than 12% should be further dried even before being placed in local farm storage. Spreading the grain in shallow beds on a hard floor will facilitate sun drying. Before storing, all trash and foreign matter should be removed by winnowing or screening.

Protection from stored grain insect damage is universally needed in warm regions. Infestations may develop from insects carried in from the field, or from insects harbored in storage structures or containers. If no control measures are invoked, heavy damage may occur in a few weeks, and complete destruction of the grain may be experienced in a few months. Thus, empty containers and storage structures should be treated with malathion before the grain is placed therein. All grain entering storage, either on the farm or in a warehouse, should be fumigated. Recommendations on appropriate kinds of fumigation are given in the Chapter on Maize, section on "pest of stored grain".

CHAPTER 11

FIELD BEANS [1/]
(*Phaseolus vulgaris*, and related species)

Present Production

The term dry beans is broadly interpreted to include all field and kidney beans of any color, size or shape, as well as lima beans and tepary beans (see chapters 15, 17 and 19 for other kinds of beans). The latter two are closely related to kidney or field beans. Field beans are the most important of the "food grain legumes" (pulses) in terms of world use, that are grown in the tropics and subtropics. They are widely grown in Mexico, Central America and the Caribbean, South America and Asia, and to a lesser extent in Africa. However, they share with other species of food grain legumes their role in cropping systems and in human diets. Dry field beans fill a similar position in farming systems as cowpeas, pigeon peas, and mungbeans, but the latter fitting the hotter more humid soils and climatic conditions. Beans in common with all other food grain legumes, store well when dry, and enter into market trade channels as staple foodstuffs, both domestic and export. The food grain legumes all are relatively interchangeable with each other as foodstuffs, subject to various local preferences.

Food Value

Beans (and other food grain legumes) are high in total protein, 20 to 25%, and thus serve to balance human diets based on cereal grains and other starchy crops. They serve as a substitute or as an "extender" of the scarce animal and fish proteins. Although the bean protein is somewhat deficient in the sulfur containing amino acids (methionine and cystine), the protein is rich in lysine and tryptophan that are deficient in cereals. Beans also contain about 2% fat, and about 50% carbohydrate (energy constituent), thus making them a nutritious food.

Utilization

Some varieties of beans and other food grain legumes have a reputation for being flatulent (generate gas in the digestive system), but it is reported that this may be alle-

[1/] Edited by Charles A. Francis, Coordinator, Small Farm Systems Programs, International Center for Tropical Agriculture, Cali, Colombia viated by soaking* and discarding the soak water before cooking, followed by thorough cooking. Plant improvement by breeding should succeed in developing new varieties that are less likely to be flatulent, and also are richer in protein and the essential amino acids - methionine and cystine. This may be done in conjunction with breeding for higher grain yields and for resistance to limiting diseases and pests.

To more fully exploit the value of beans in the agricultural economy, yields of beans per hectare must be substantially increased. To date, comparatively little application has been made of agricultural science and technology to improved bean production. However, local experiments and field trials have indicated the feasibility of readily increasing productivity of the crop by 2- or 3-fold with present knowledge and materials, and that further increases are possible when research has been completed on breeding improved types and testing superior cultural practices for local conditions. The benefits of invoking modern science and technology will be to increase the volume of the crop being produced, and to greatly reduce the net cost of production per kilo. By so doing, it will be feasible to rapidly improve the quality of rural diets, and to produce a salable cash crop for which there is market demand, both for domestic and export trade. The following review indicates promising methods of increasing production.

Adaptation

Climate

Field beans are annuals that belong to the legume family. In common with other legumes, they are capable of satisfying a major part of their nitrogen needs through fixation of nitrogen from soil air by means of root nodules containing specific forms of bacteria (*Rhizobium* spp.). Thus, beans are essentially independent of both soil nitrogen and fertilizer nitrogen. However, when grown as a very short-season crop, the addition of some nitrogen fertilizer or the growing of the crop on fertile soil is an asset for rapid growth and higher yields. The residual effect of growing beans on land is to improve fertility for succeeding crops.

There are significant differences between bean varieties in their tolerance of heat and drought. Thus, tepary beans

* Soaking is more effective in water containing about ½ gram of soda per liter of water; soaking for several hours.

(Phaseolus acutifolius) have the reputation of producing a crop in 60 to 90 days in hot, dry climates, providing soil moisture is adequate for that short growing and ripening period. Other tropical varieties may require as much as 120 to 150 days to mature, and these differ in tolerance to heat. There are varietal differences also in reaction to air humidity, but in general beans are most productive in regions with lower humidity, largely because of diseases and insect pests that attack leaves and stems of beans in humid regions. Beans are most successful in areas where rainfall is light during the latter part of the growing season. (Other legumes thrive when air humidity is too high for higher bean yields.)

Soil

Beans are grown most successfully on soils of medium texture (loams), that are well drained. Where occurrence of rains is uncertain, soils should be 60 to 100 cm deep, so that roots may draw on these soil moisture reserves. Shorter season varieties have shorter root systems. Beans are grown quite successfully as irrigated crops, with yields substantially higher than most beans grown with natural rainfall. Beans are not heavily dependent on nitrogen in soils, but they have comparatively higher requirements for phosphate and other major minerals (potassium, calcium, magnesium, and sulfur) than the cereals, since their ultimate composition is higher in such elements. It is believed that the need for essential "trace" elements (manganese, iron, copper, zinc, boron and molybdenum), needed in rather small amounts, has generally been overlooked. It should be noted that the relatively high mineral contents of beans are an important contribution to the nutritive value of beans, as well as being indicative of fertilizer needs for higher yields. Fertilization to augment the soils capacity to supply these elements is important in bean culture (see section on fertilizers). Since all food grain legumes are somewhat deficient in sulfur-containing amino acids, attention to the sulfate supply in soils and fertilizers is indicated.

Description

Dry beans, including all forms of common or "kidney" beans, lima beans, and tepary beans, may be bushy or trailing in growth habit. In general, the bush types are preferred for commercial production, since they are largely determinate in growth and most of the crop ripens at one time, thus facilitating mechanical harvesting. The plant has a well branched root system. The bush-plant type has a strongly developed central stem and branches, bearing trifoliate leaves. Leaves and stems are somewhat hairy. Flowers are small, and vary in color from white to bluish. The flowers are self-pollinated, and hence the seed generally breeds true to type. Pollinated flowers produce pods, straight to sickle shaped, 10 to 15 cm long, containing 5 to 20 seeds. Mature dry beans of different varieties may range in color from white to pink, red, speckled, and brown to blue-black. They also vary greatly in size, ranging from 20,000 to 60,000 seeds per kilogram. Some vegetable varieties of beans are grown for their edible pods and immature beans; these have non-fibrous pods. All dry bean varieties may be harvested prematurely, for cooking and eating as shell beans. Climbing bean varieties are longer season, but are preferred by small farmers for their associated planting systems, particularly with maize.

Improved Varieties

The best description of the ideal bean variety has not yet been determined. Obviously the structure of a variety to satisfy the needs for mechanized agriculture would not be the same as for a bean that would be grown in association with another crop such as maize. In either case, desirable plant traits for improved field bean varieties would include erectness so that pods are held above the ground, with grain ripening uniformly, and in which the beans do not shatter out of the pods when mature. These traits are compatible with adaptation to specific climatic and soil conditions, high productive yield potential under favorable conditions, and resistance or tolerance to locally important diseases and insect pests. The shape, size and color of seed are heritable, and may be combined with other desired traits.

A considerable number of research institutions, particularly in Latin America, North America and Europe, have made extensive collection of bean types and strains; and these collections should be drawn upon to conduct local or regional field tests in the tropics and subtropics, to identify any selections that give superior performance. The world collection is being assembled at the International Tropical Agricultural Center (CIAT), Cali, Colombia. Since beans generally "breed-true", there is no difficulty in rapid multiplication of the outstanding selections. Also, farmers may grow their own seed without loss of hereditary traits; although guidance will be needed on maintaining identity and producing viable, disease-free seed.

Plant breeders should be encouraged to hybridize promising parental stocks, each of which have desired traits, to combine such traits into individual strains. Such programs have been highly successful in developed nations of temperate zones, and should serve as guides for similar progress in the many tropical regions where beans are adapted. Two characteristics in addition to yields that require more attention than they have received are: (1) the improvement in protein content and sulfur-containing amino acids (methionine and cystine) when grown in soils of higher sulfate content, and (2) differences between varieties in ease of cooking and tendency to flatulence as foods. Black and red seeded varieties have been observed to be distinctly better adapted to the more humid semitropics than white seeded types, being generally more vigorous and disease-free. Recent tests made on isogenic lines of black and white types from Costa Rica show the black seeded ones containing appreciable quantities of tannin. The presence of tannin would also explain the distinctly lower nutritional value of the black-seeded varieties.

Culture

Fertilization

Beans respond strongly to adequate supplies of mineral nutrients. Application of animal dung in generous amounts produces favorable crop responses, particularly when applied in shallow furrows that are then partially closed and the seed planted above the manured bands. Broadcasting dung on top of the prepared seedbed is a less efficient method, since much of the benefit is not realized unless dung is incorporated in the soil. Dung is highly variable in composition, and any standardization of the amounts required to increase yields is difficult to achieve.

Commercial fertilizers are usually evaluated for crops in terms of their nitrogen, phosphorus, and potassium contents, with emphasis on nitrogen. While this is appropriate for cereals and other non-legumes, the phosphorus and potassium contents are most important for beans. Supplying phosphate in a usable form is uncertain on many tropical soils because of the soil's capacity for promptly converting the fertilizer phosphate into insoluble forms, which are unavailable to crop plant roots. The most effective method devised to date is to place the phosphate (and potash) in bands in shallow furrows, cover lightly, and then place seed above these bands.

The best method for determining phosphate and/or potash needs is by field trials with various amounts and kinds of fertilizer. Without such trials, it is useful to make laboratory tests on representative soil samples, to determine the apparent soil fertility. The fertilizer then is selected to correct the soil deficiencies to meet crop needs. Wherever ordinary superphosphate is applied, the amounts of sulfur, calcium, and magnesium carried in the superphosphate will be sufficient to meet bean requirements for these elements. However, if concentrated superphosphate is used to supply phosphate, this does not contain sulfate, and will not correct soil sulfur deficiencies, if present.

On highly weathered tropical and subtropical soils, there is a strong probability that one or more of the essential "trace" elements may be so low as to seriously affect yields. These elements are manganese, iron, copper, zinc, boron, and molybdenum. The deficiencies are less likely to be found where animal manures are applied to crop lands, since manures contain some of these elements. On soils where application of fertilizers does not produce increased crop yields, it is likely that trace element deficiencies constitute the limiting factor. Detailed studies are then needed to identify the element required, and the amounts to be added to the soil.

It should be clear that the use of fertilizers and of trace element compounds should be based on evidence that the inherent nutrient supplying power of the soil will not satisfy crop plant needs for higher yields. The amounts of each element that are needed must be determined by field tests, but preliminary guides may be provided by the results of trials conducted in other regions that are similar in soil and climate.

Seed Bed Preparation

Manures and/or fertilizers should be incorporated in the soil during seed bed preparation. Beans should be planted on a mellow but firm seed bed, free from clods and coarse trash. Germinating bean seed elongates the young stem and lifts the cotyledons (seed leaves) through the covering soil layer. Strong soil crusting may prevent the cotyledons from emerging. To minimize this hazard, beans should be planted shallowly in moist soil to facilitate prompt germination.

Planting

Beans may be broadcast, drilled in close rows, or planted in rows to permit cultivation. They may be grown in monoculture in a rotation with other crops or in association with them. Cultivated rows, 50 to 60 cm apart require 40 to 50 kg of seed per hectare, depending on seed size. Drill planting in rows 15 to 25 cm apart is used where weeds are not serious competitors of beans, and 90 to 100 kg of seed are planted per hectare by this method. Broadcasting is not an efficient method of planting, and this type of culture does not favor weed control. (<u>NOTE</u>: No recommendations are made on treating seed before planting, since such treatments are poisonous to man when surplus seed is eaten; and must follow the in-country regulations.)

Weed Control

Planting in rows 50-60 cm apart, at seeding rates to provide at least one growing plant per 10 cm of row, permits weed control by early hoeing or cultivating. Any damage to the root system by tillage methods or weed competition will seriously retard plant growth and yields. Weeds should be killed while very small, before they compete strongly with the bean plants. In broadcast or closely drilled plantings, the use of specific herbicides selected to kill the kinds of weeds present without harming the beans is an effective way of combating weeds.

Diseases

Beans may be attacked by a number of serious diseases, including bacterial blights, leaf spots, leaf rust, leaf mosaics, root rots and nematodes. High air humidity accentuates most of these diseases; and, thus, bean production is most likely to be profitable in regions that are generally lower in humidity. Planting disease-free seed reduces certain bacterial blights, leaf spots, and mosaics. However, where available principal reliance should be placed on growing resistant varieties. Good field sanitation is also essential; beans should not be grown on the same land in successive years, and all crop residues should either be fed to livestock, or incorporated in the soil to reduce the danger of carryover of the disease inoculum.

Insect Pests

Beans are attacked by various insects, including bean weevils (seed borne), bean beetles that feed on leaves, leaf hoppers, and aphids and such insects as the white fly that transmits viruses. Bean weevils are controlled by fumigating seed before planting, and by field sanitation. Outbreaks of plant infesting beetles and larvae may be treated by dusting with pyrethrum, malathion, or other appropriate insecticides. Weed growths bordering the fields and insects on the weeds should be eliminated before the bean crop is seeded. This prevents initial infection by insects which transmit viruses from border plants. (see footnote)

Footnote: For further information on Crop Protection, see Chapter 4 in book on "Tropical Agriculture" by Wrigley, (Reference list following Chapter 40).

Harvest

It is important to grow varieties that are upright, so that pods do not touch the ground, and varieties in which the pods do not dehisce when ripe, since ripe seed that shatters out of pods is largely lost. These traits are heritable and may be combined with high yielding potential. The beans are fully mature when the pods lose color, but subsequent drying to 10% moisture content is completed faster while on the standing plants. If harvested earlier, additional drying on drying floors in sunshine is necessary to reduce moisture on the low level that will prevent molding in storage. Threshing may be done by hand flailing or by a thresher suited for wheat or sorghum, adjusted to avoid undue cracking of the beans.

Storage

Well-dried beans should store safely, if protected from rains or other moisture. The greatest hazard is that of stored grain insects, which may cause severe damage in a short time in warm weather. All empty storage structures and containers should be treated with malathion before being filled with the new crop. The new crop should be fumigated as it goes into storage, and the fumigation repeated whenever there is evidence of new insect infestation. See the section on control of stored grain insects in the Chapter on Maize, for further information.

CHAPTER 12

COWPEAS [1/]

(*Vigna unguiculata*)

(Synonyms with varietal connotations: *V. sinensis*, *V. cylindrica*, *V. catjang*, and *V. sesquipedalis*)

The cowpea, sometimes known also as southern pea, is a warm-season, annual, herbaceous legume. There are at least four easily recognized plant types -- erect, semi-erect, prostrate (trailing), and climbing -- and although differences are mostly genetic, reduced light contributes to vinyness. Plants are fairly leafy with smooth, dull to shiny trifoliate leaves. The growth habit ranges from indeterminate to fairly determinate, but the plant typically continues to blossom and produce seed for an extended period. The non-viny type tends to be more determinate in blooming habit than viny types; and there are improved varieties that blossom over a short period, so that ripened pods may be harvested at one time. With viny (trailing) types, the plant is still blooming when the first pods are ripe, and repeated harvest are necessary to keep pace with ripening pods.

The cowpea flowers are solid white, white with purple markings or solid purple in short racemes. Most cultivars produce medium (20 cm) to very long (50 cm or more) peduncles on which multiple racemes are borne. A good variety may produce two to three pods per peduncle, but often four or more pods may be carried on a single peduncle. The presence of such long flowering stalks is one of the most obvious distinguishing features of cowpeas in comparison with other species. This characteristic facilitates both hand and mechanical harvest. The open display of flowers above the foliage combined with the presence of floral nectaries also contributes to visits by pollinating insects.

The pods are smooth, 15 to 25 cm long, cylindrical and somewhat curved. They are usually yellow when dry, but some varieties have purple or brown coloration. The seeds are bean shaped but are shorter in comparison with width, and varietal colors may vary from solid buff, clay, white, maroon, purplish or nearly black to variously spotted, speckled, or marbled. Some varieties characteristically have a darker colored spot on the hilum (seed attachment), often called an "eye." With this range in varietal colors, it is feasible to select varieties so as to produce seed of the type readily accepted in markets available to the producer. Varietal seed size also

[1/] Edited by K.O. Rachie, Leader, Grain Legume Improvement Program, International Institute of Tropical Agriculture, Ibadan, Nigeria ranges from 3,500 to 9,500 per kilo; desired size and color of seed may be combined by the plant breeder with the desired growth habit and yielding ability. Since the cowpea is self-pollinated, growers may save their own seed without loss of hereditary traits.

Adaptation

Cowpeas are a warm-weather annual crop. Compared to the bean (*Phaseolus vulgaris*) cowpeas being drought resistant will tolerate lower rainfall and humidity during the later growth stages of pod formation and filling when grown on soils of some depth that supply moisture. The two crops fill about the same role in farming systems; and the choice should be based on relative adaptation and total grain yields. Phaseolus beans are seldom grown below 1000 meters in hot, irregular rainfall zones in tropical Africa.

Cowpeas are adapted to a wide range of soils, from sandy to heavy loams, fertile to less fertile soils, including soils that are quite acid. This does not mean that the crop prefers infertile or acid soils, but that it tolerates such soils under conditions of adequate rainfall. The crop is *not* adapted to soils with poor drainage.

Production Areas

This crop species is native to Africa, and the greatest use of the crop is in Africa, although it is also grown extensively in Latin America and southeast Asia. Nigeria, Niger, Upper Volta, Uganda, and Senegal grow cowpeas for market, but they are widely grown as a subsistence crop for home use in nearly all African countries south of the Sahara. It is the predominant food grain legume in African regions of moderate to abundant rainfall. Cowpeas also have achieved some prominence in the Far East. There is ample evidence in the Americas that cowpeas of adapted varieties are more productive than phaseolus beans in regions of Central and South America at lower elevations where temperatures and less equably distributed rainfall prevail. Cowpeas are best adapted in Africa to the subhumid to semiarid regions (250 to 1000 mm rainfall). They are much more tolerant of high temperatures and extended drought periods than phaseolus beans, which are largely confined to higher elevations.

The countries reporting yields per hectare exhibit great differences in productivity. Some country yields were two to three-fold greater than the average for all African countries, and there was a three-fold difference between the high and low yielding countries of Asia. From the research results on cowpeas, improved cultural practices may produce four-fold increases in yield on the same varieties. Even greater increases were obtained through judicious insect control. Average yields of one ton or more per hectare should be attainable with adapted varieties where rainfall is moderate to abundant. In general, this food grain legume has been neglected with respect to the application of science and technology, including both breeding and testing programs to develop improved varieties as well as studies on methods of culture to maximize yields.

Two varieties, asparagus bean (*V. unguiculata* var. *sesquipedalis*) and catjang (*V. unguiculata* var. *cyclindrica*), are grown primarily in South Asia, but are believed to have potential wherever cowpeas are adapted.

Cowpeas as a Food

Mature, dry cowpea seed (grain) averages 23 to 25 percent total protein, 57 percent carbohydrates, 1.3 percent fat and 3.5 percent minerals. Cowpeas constitute an easily digested and nutritious food. Although the protein is somewhat deficient in the essential amino acids methionine and cystine, as compared to animal proteins, it is comparatively rich in lysine and tryptophan that are characteristically deficient in all cereal grains. Cowpeas, therefore, constitute a valuable foodstuff to supplement cereals which have adequate methionine and cystine, and other starchy foods in the human diet. They may be used as "extenders" of animal proteins, which are easily prepared for food in home cooking. There seems to be much less of a problem with flatulency than with phaseolus beans, and hard seed coats are generally absent. Green cowpeas are widely used as a vegetable. A very important use in many parts of Africa is the tender green leaves as a pot herb (spinach).

Varieties

There are a wealth of varieties in various collections which have been made by research agencies, but many of these have not been field tested in tropical climates suited to cowpeas. In addition to plant type, testing is needed to identify yield capacity under favorable systems of culture, and the relative resistance or tolerance of varieties to the diseases and insect pests of different areas. Marked differences have been observed in a few locations, but significant research has been limited. Some of the testing in Nigeria, the United States, and Puerto Rico may have direct application to the tropics and subtropics on other continents. Varietal testing should be carried out with cultural practices known to favor increased yields. IITA in Ibadan, Nigeria is now the center for worldwide collection and testing of germplasm.

Fertilization

Being a legume, cowpeas do not need nitrogen fertilizers. Although the requirements for phosphate and potash, as well as calcium, magnesium and sulfur are relatively high, natural or residual nutrients are frequently adequate. Most tests in the lowland tropics have not shown responses to P or K. This may be expected to change as yield levels are raised and when the crop is grown on more depleted soils. Strong responses to the sulfur have been shown on some savannah soils. Therefore, the responses that have been credited to ordinary superphosphate may have been in fact due to sulfur (concentrated superphosphate contains no sulfur).

The requirements for "trace elements (manganese, iron, copper, zinc, boron, and molybdenum) are not well worked out for cowpeas; and the probable deficiencies occuring in various soils of the tropics are very poorly defined at present. It is virtually certain that "trace" element deficiencies constitute limiting factors for cowpea production in certain localities. A preliminary identification of these may be made by noting conditions under which mineral fertilizers appear to give limited response, and where applications of dung are clearly beneficial. There is then the research problem of determining which trace element(s) may be in short supply, and devising practical ways of correcting the deficiency. This is a common problem with all cropping in the tropics, and a direct research attack should have wide benefits.

Seed Bed Preparation

The seed bed for cowpeas should be firm, free of clods and coarse trash, and moist at the time of planting. Fertilizers, if required, are best applied in bands below the seed row, so as to avoid undue interaction with soil that tends to convert phosphates to unavailable forms. It is recommended that placement of the mineral fertilizers, and/or dung, be made in the bottom of shallow furrows. The fertilizer is then covered with an additional 2 or 3 cm of soil. Mineral fertilizer "bands" should be placed a little to one side of the seed row to avoid burning of new roots.

Plantings should be made in moist soil, to foster prompt germination. Soil crusting produced by rains and subsequent drying may cause poor seedling emergence and thin stands of plants. Broadcast planting is not recommended. Row planting permits more effective placement of fertilizer and facilitates weed control and crop harvest. Spacing of rows should be adjusted to the robustness of the variety, from 60 to 100 cm apart. Seed should be spaced in the row to produce one plant per 5 to 12 cm for erect forms 30 to 60 kg of seed planting one hectare; for spreading types spacings between plants in the row should be 20 to 30 cm or at rates of about 10 to 15 kilos per hectare. On fields being planted to cowpeas for the first time, particularly in regions where the crop is not common, seed should be inoculated with a fresh culture of cowpea bacteria to insure desirable development of root nodules. Inoculation should be made just before planting.

Weed Control

Weeds, if present, will greatly reduce yields and should be removed while still small, before competition with the crop has become serious. Efforts should be made to reduce or prevent damage to the cowpea root system, whether by pulling weeds, hoeing, or tillage. Weed control by treatment with selective herbicides selected to kill the weed species present without injury to the crop may become a practical method if and when a satisfactory weedicide is found reliable, particularly when prompt removal of weeds by other means is impossible. Weed control is much less of a problem than it would be if nitrogen fertilizer were used.

Plant Diseases

Cowpeas are generally considered not as subject to epidemics of diseases as many other food grain legumes although in Africa, where the cowpea originated, the plants are much more susceptible to diseases than any of the other grain legumes grown. The most important diseases are wilts and rootknot diseases (soil borne) that afflict the crop, as well as leaf spots, mildews, viruses, and rusts. The control measures that are most effective are: (1) the use of clean seed of varieties that have resistance to the diseases that are locally prevalent, and (2) field sanitation. Sanitation includes removal of all top growth after the crop is harvested (preferably as feed for livestock), and avoiding planting cowpeas on the same land in successive years. Both methods, especially the latter, greatly reduce the amount of inoculum present when cowpeas are next grown on the field.

Insect Pests

The weevils that infest seed may seriously reduce plant stands. As a preventive, seed should be dusted with malathion or other suitable insecticide immediately after harvest. In tropical Africa aldrin is commonly recommended. If insects are are suspected to be in the seed at planting time, it should be fumigated to kill weevils and larvae that feed on growing plants. Field sanitation also is useful in preventing build-up of damaging insect pests. Serious outbreaks of insects should be treated promptly with insecticides that are appropriate to the species. Malathion is a general purpose dust, but others may be more effective depending on the species to be controlled.

Harvesting and Threshing

The more upright, half-bush growth habit greatly facilitates harvest of ripe pods. This plant form also tends to produce most of its blossoms within a short period, so that most of the ripe pods can be harvested in a single picking. While this situation favors commercial type picking, the trailing growth habit and the continued production of pods over longer period of time may produce substantially greater total yields. Where the supply of hand labor is not a limiting factor, the trailing plant type and extended period of harvest may be advantageous. However, the pods harvested from such plants will be variable in moisture content of the seeds, and final sundrying on drying floors is a prime requirement. Whatever the method of harvest, the grain must be reduced in moisture content to 10 percent for safe storage. Higher moisture induces rapid molding in warm weather and quickly makes seed for planting nonviable.

Thoroughly dry pods are easily threshed by hand flailing or machine threshing. There should be no splitting of seed to produce high quality grain.

Control of Storage Insects

Cowpeas are susceptible to serious damage by storage insects of several types. Some infestations by weevils that have occurred in the field will carry over into storage unless promptly treated. Drying of seed and threshing should not be delayed, so that fumigation of newly harvested grain stops possible insect damage. Empty storage structures and containers should be treated with malathion or equally effective insecticides to destroy insect pests harbored therein. The new crop should be fumigated as it enters storage, and the fumigation repeated when there is any evidence of reinfestation. (For further details on fumigation, see the chapter on Maize, section on control of storage insects.)

CHAPTER 13

CHICKPEAS [1/]
(*Cicer arietinum*)

Other Common Names: garbanzo, gram, bengalgram

Distribution

Chickpeas are grown widely as a cool season annual in a broad belt through the Mediterranean region to the sub-tropical and tropical regions of the Near East and Asia, and at higher elevations of the true tropics on other con-tinents. In terms of land areas occupied by the crop, India and Pakistan are the greatest users, but other important countries include Burma, Iran, Turkey, Spain, Portugal, Morocco, Ethiopia, Tanzania, Mexico and Chile. The crop has received relatively little attention in terms of applied science and technology, despite its very wide use as a pre-ferred food in both rural and urban regions. Average yields reported in crop statistics are low, but recent research results in Iran and India show that 3 to 4 fold yield increases are feasible by the application of better cultural practices, and planting of higher yielding types.

Food Status

Chickpeas average 20% protein, 4.0 to 4.5% fat, 55% carbohydrate and 2.5 to 3.0% mineral content. In common with other legumes, it is somewhat deficient in the amino acids methionine and cystine; but it is a useful supplement to cereals and other starchy foods that are rich in methionine and cystine, but deficient in lysine and tryptophan in which chickpeas are rich. The chickpea is rated as being highly digestible, particularly the white or cream colored seed types; and its relatively high content of carbohydrates, fats and minerals make it a useful food in human diets. It is particularly desirable in diets that are low in animal proteins, that commonly occur in the tropics and subtropics. It, however, causes flatulence, which may become serious in children.

Chickpeas are widely sold in urban food markets through-out the tropics and subtropics, and thus constitute an ex-cellent cash crop for both domestic and export trade. It is used both as a green vegetable as well as dry pulse or

[1/] Edited by J.S. Kanwar and K.B. Singh, International Crops Research Institute for the Semi-Arid Tropics, Hyderabad 500016, A.P., India dhal. When well-dried, the grain is not perishable and may be handled as a staple foodstuff.

Utilization

From the standpoint of human food, chickpeas are generally interchangeable with the other food grain legumes, although there are distinct local or regional preferences for different species and seed types. It is common to find several species of food grain legumes offered for sale, in proximity to each other at many food markets. From a cropping point of view, chickpeas are somewhat interchangeable with the other cool season annuals - lentils, field peas and broad beans. Chickpeas also may be grown as the principal crop in regions where there is a short season that has enough rainfall to grow only one crop. The crop appears to be widely regarded as a subsistence food crop; and when a favorable season produces a surplus, the excess is marketed. With the advent of higher yielding varieties and improved culture to make production more dependable, chickpeas as a staple food crop for marketing may be expected to increase in popularity.

Adaptation

Climate

Chickpeas are adapted to cool to moderate temperatures during growth, but tolerate considerable heat during the fruiting and ripening period. In India and Pakistan which have about 85% area of the world under the crop, it is primarily grown on conserved moisture in winter. They respond to moderate rainfall, but are adversely affected by heavy rainfall in warm seasons because of plant diseases and insect pests. Crop culture is adjusted to these climatic conditions by planting at the onset of winter rains in the Mediterranean region and the Near East, and at the onset of the monsoon rains in winter or early spring in other Asian countries. At higher elevations in the true tropics, the crop is planted when 'rains' begin; which is the cooler season of the year. Under irrigation, chickpeas are planted at the beginning of the cool season. Where rainfall distribution permits double cropping, chickpeas follow the principal warm season crop - maize, rice, sorghum, etc. Quite often it is grown as a relay crop and planted in standing crop of cotton. Chickpeas will complete growth and ripening in 4 to 5 months.

Soils

Chickpeas are grown on a wide variety of soils, but the crop does not tolerate wet soils or soil salinity. Very heavy soils may cause problems in emergence of seedlings. The crop has a high requirement for mineral nutrients, but does not need nitrogen fertilizers, except in a small amount as a starter. It derives its nitrogen from root nodules produced by chickpea strains of nodule bacteria. On land that has not grown chickpeas previously, it is essential to inoculate the seed with fresh cultures of chickpea root nodule bacteria. No further inoculation should be necessary for subsequent crops.

Fertilization of chickpeas generally has been neglected, but the crop is known to have high requirements for phosphate, potash (on some soils), calcium, magnesium, and sulfur, ordinary superphosphate, supplemented with potash, will supply all of these, if applied in appropriate manner (see section on fertilization). By analogy with other legumes, it is expected to have specific requirements for the "trace" elements, particularly, zinc, to support high yields; and the deficiencies of certain soils in supplying these elements remains to be explored. The statistics on average yields do not reveal the probable yield potential under favorable cultural practices.

Description

The chickpea is an erect annual, 45 to 60 cm in height. The plant is well-branched, with pinnate leaves having 10 to 20 leaflets. The flowers are borne singly on short stalks, white or tinted in color. Seeds are borne in short pubescent pods, 2-2½ cm long and 1 cm wide, 1 or 2 seeds per pod. Seeds are large, ½ to 1 cm across, wrinkled with a point at one end; and varieties may have black, red, white, green or pinkish seeds. In regional types, small black seeded types seem to be associated with earliness and tolerance to adverse soil and climate conditions; but the white seeded types appear to be higher yielding under favorable growing conditions. However, genetic studies indicate that plant and seed traits are inherited somewhat independently, so that various combinations of heritable traits are possible. Germination of seed is hypogeal, meaning that the cotyledons (seed leaves) remain in the soil and the growing sprout pushes through the soil to emergence. Soils that crust badly may interfere with seedling emergence.

The chickpea has a tap root, rather well-branched. It permeates soils to some depth, permitting sustained growth without appreciable rainfall, where significant storage of moisture in the soil profile has occurred during the period of rains. On shallow soils, such tolerance of drought is not possible.

Varieties

Extensive collections of regional types and "land races" have been made in India, Iran, Pakistan and some other countries where chickpeas are an ancient food crop. These types have been the source of many selections, varying greatly in plant and seed characters, in productivity, tolerance or resistance to plant diseases and to the insect pests of the crop. A significant assembly of these promising selections is available in the countries listed above, and also at the U.S. Department of Agriculture experiment station in Puerto Rico. The International Crops Research Institute for the Semi-Arid Tropics at Hyderabad (India), is a world center of research for chickpeas, where large collections are available.

Improved varieties have been chosen from this collection for specific regions in India, Iran and Pakistan; and multiplication and distribution of seed is underway. Other selections may be better suited to differing ecological conditions. Active breeding programs to combine resistance to prevalent plant diseases and insect pests, with higher productivity and desired seed qualities, are underway in a few countries. The evaluation of existing selections and the breeding to develop improved adaptation to specific regions appears most promising. However, such improvement programs are useful only to the extent that they are combined with cultural practices that permit expression of productive potentials.

Culture

Fertilization

Chickpeas do not require nitrogen fertilizers when naturally or artificially inoculated with chickpea root nodule bacteria. However, the crop does have substantial requirements for mineral nutrient elements, and virtually all tropical and subtropical soils are not naturally well supplied with these elements. Fertilizers and soil amendments should be used to correct soil deficiencies. Effective use may be made of animal dung as a substitute for fertilizers, or as a supplement. For this crop, the dung's value is that of supplying minerals, rather than nitrogen. It's role in providing "trace elements" may be decisive, although more experimental evidence is needed to explain the precise reasons for benefits from dung. The "trace elements" are manganese, iron, zinc, boron, copper, and molybdenum. However, dung is also established as a source of readily available phosphorus.

The use of ordinary superphosphate fertilizer will automatically supply calcium, magnesium, and sulfur as well as phosphorus; but concentrated superphosphate carries no sulfur. Ordinary superphosphate is preferred for legumes. Potash is likely to be deficient in regions of moderate rainfall.

The need for mineral fertilizers and supplements is best determined by well-designed field trials. Where such results are not available, the use of laboratory tests on representative soil samples from specific fields should provide useful guides to fertilizer needs. Laboratory indications should be confirmed by field trials.

General recommendations should provide phosphate and potash applications at the ratio of 2 parts phosphate to 1 part potash; the fertilizer placed in shallow furrows at the rate of 50 to 100 kg/hectare; the furrow partially filled with soil, on which seed is then placed and covered with 2 to 3 cm of soil. However, where wilt is common and moisture is limited, deep planting at 10-12 cm is recommended. In such cases, side placement would be desirable. Dung may be applied with the fertilizer, or alone when fertilizer is not available. The dung may serve as a practical, but limited, source of the trace elements. Specific recommendations on the need for trace elements must be based on field experiments. Such research may be highly productive; some experiments have shown a doubling of yields where trace element deficiencies have been recognized and treated appropriately.

Broadcast application of fertilizers is not recommended; furrow placement provides nutrients to seedlings when they have the greatest need, and largely bypasses the inactivation of phosphate fertilizers by interaction with the soil.

Seed Bed Preparation and Planting

Chickpeas should be planted on seed beds that are free of large clods and trash, rather firm but not fine. It should be moist to considerable depths. All perennial and annual weeds should be killed or removed by weeding.

Planting time should be adjusted to the season; planting at the beginning of the cooler growing period, when moisture is expected to be adequate, is highly essential.

Row planting is recommended; broadcast plantings are wasteful of seed and do not permit effective placement of fertilizers. Row plantings also facilitate weed control, pest control treatments, and harvest. Row spacings should be adjusted to the plant size of the varieties, 30 to 100 cm apart. Seeding rates should provide one plant per 10 to 30 cm of row, the closer spacing used when soil moisture supplies are expected to be reasonably adequate. The amounts of seed will range from 50 to 100 kg/hectare depending on the seed size of the variety. Planting seed should have high viability; above 80% germination. (NOTE: No recommendations are made on treating seed before planting, since such treatments are poisonous to man when surplus seed is eaten; and must follow the in-country regulations.)

Weed Control

Chickpeas are not strongly competitive with weeds, and weed control is necessary. Weeds should be killed while quite small to eliminate competition with the crop. Weeds should be removed by minimum damage to the chickpea root system, whether by pulling, hoeing or other tillage. Generally one weeding after 45 days of emergence is enough to keep the weeds under control. For weed control by herbicides, there are specific herbicides that kill weeds without injury to chickpeas; these may be best used when prompt control is needed and labor is not immediately available.

Disease Control

Chickpeas may be attacked by a variety of leaf and stem diseases and wilts. These are most serious in periods of continuing rains and high humidity, particularly at higher temperatures. In general, the best means of coping with these are: (1) to plant resistant strains or varieties of the crop, (2) practice crop rotation so that the land is not cropped to chickpeas in successive years, (3) use disease free seeds from the localities where the disease does not occur, and (4) destroy diseased debris either by burning or burying underground. Breeding programs to develop strains that have greater disease resistance is the most promising attack for future progress.

Insect Pest Control

The most damaging insect pests vary with the region. They may include seed maggots, leaf miners, thrips, bollworms, weevils, pod borers and mites. In general, such pests are favored by higher humidity at warm temperatures. There are no general treatments; the treatment must be adjusted to the specific insect pest that is damaging. General purpose insecticides useful in pest control are available and should be used when pests threaten to become serious. There are specific pesticides which control the pod borer.

Fortunately, there are distinct varietal and strain differences in resistance to particular pests. These available resistant strains should be used where possible and breeding programs undertaken to combine resistance with other desired traits as a long time improvement program.

For further information on Crop Protection, see Chapter 4 in book on "Tropical Agriculture" by Wrigley. (Reference list following Chapter 40.)

Harvest

It is essential that the seed be dried to about 10% moisture for safe storage without molding. Unless there is danger of losses by shattering of seed from pods, plants should stand in the field until seed is well dried. Such sun drying is highly effective. If earlier harvest is needed, subsequent sun drying on hard surfaces should occur promptly.

Threshing is accomplished by hand flailing, taking care not to crack or split the seeds. Machine threshing is quite feasible, if adjusted to avoid seed cracking and splitting. If seed moisture has not been reduced to 10% at threshing time, further sun drying in thin layers on hard surfaces is required to avoid molding in storage.

Storage Insect Pest Control

Losses from insects infesting stored seed and grain are invariably serious unless suitable treatments are applied. All empty storage structures and containers should be treated with malathion or equally effective insecticides before the new crop is placed in storage, to kill all insects therein. The new crop must be fumigated before being put in storage to kill insects already present; and again fumigated whenever there is any evidence of reinfestation. For further details of fumigation, see the Chapter on Maize, section on storage insect pest control.

CHAPTER 14

LENTILS 1/
(*Lens culinaris*)

Geographical Distribution

Lentils are an ancient food crop, widely grown as a cool season annual in the Mediterranean region, through the Near East and subtropical Asian countries. It is also important in higher altitude tropics in other continents. Countries with the greatest production in 1971 include India, 754,000 ha, Pakistan, 140,000 ha, Turkey, 103,000 ha, Syria, 129,000 ha, Iran, 55,000 ha, Ethiopia, 180,000 ha, Russia, 60,000 ha, Egypt, 20,000 ha, Morocco, 35,000 ha, Algeria, 23,000 ha, Jordan, 22,000 ha, and the U.S.A., 27,000 ha. There are great differences in average yields per hectare between countries, as much as 4-fold differences, the highest yields being reported by Egypt with 1,930 kg/ha and the lowest of the countries listed above being India and Morocco with averages of 470 and 390 kg/ha, respectively. The yields are 3 to 4 times as high as the national averages. These reports suggest that this ancient crop has great undeveloped potential, which has remained latent through neglect. Lentils have received but little research attention even in developed countries; and there have been scant efforts to apply modern science and technology to improved lentil production in less developed countries. The crop has remained important despite such neglect, because of its popularity as a foodstuff, and the special niche it holds in farming systems.

Food Values

Lentils are a high-protein foodstuff, that substitutes for animal proteins in the tropics and subtropics where human diets are generally deficient in proteins. Lentils average 24 to 25% protein, 60% carbohydrates, 1.0% fat and 3.0% mineral matter. The protein is somewhat deficient in two amino acids - methionine and cystine, but is well supplied with lysine and tryptophan. Lentils are an excellent supplement to the cereal grains that are characteristically low in lysine and tryptophan, but higher in methionine and cystine. Since lentils are rich in carbohydrates, and are easily cooked and quite digestible, they constitute a nutritious foodstuff. Lentils may develop hard seed coats depending on variety and environment in which grown. The hard

1/ Edited by F.J. Muehlbauer, Research Geneticist, Western Region, Agricultural Research Service, U.S. Department of Agriculture, in cooperation with Washington State University, Pullman, Washington 99163 and James M. Schalk, Research Entomologist, Vegetable Laboratory, Northeastern Region, Agricultural Research Center, Beltsville, Maryland 20705 seed coats are responsible for increased cooking time as is the case with the bean, for example.

Lentils are interchangeable with other food grain legumes as a high-protein foodstuff, despite strong local or personal preferences for individual types and kinds of food grain legumes. In urban food markets, it is customary to see several food grain legumes offered for sale side by side, such as lentils, chickpeas, beans, peas, cowpeas, mungbeans, and broadbeans. Although lentils have specific attractiveness as a food, they must compete with other species in terms of unit costs, and such costs are reflections of relative production efficiencies. Improvements in crop yields are needed to expand the usefulness of the crop.

Utilization

In common with other food grain legumes, lentils have a reputation for improving soil fertility of land on which they are grown. This is because of the residual higher nitrogen content of the soil, contributed by the nodulated root system. In a general sense, lentils may be used interchangeably with the other cool-season, food grain legumes - chickpeas, peas, and broadbeans - in farm cropping systems. The choice among these is influenced largely by relative yields, and net returns to the grower. As a group, these food grain legumes are generally accorded a minor role in cropping systems because other crops have been more productive and yield greater net returns. The application of science and technology to lentils (and other food grain legumes) should raise yields, as shown by some field experiments in India, Iran, and Pakistan. The increased yields, resulting from improved varieties and cultural practices, should be valued in terms of market prices to determine gross and net returns for the crop. Lentils have the potential for becoming a major crop, as well as a crop that fits a convenient place in a cropping system, as a cool-season short-season annual grown in conjunction with a warm-season principal crop.

Adaptation

Climate

Lentils are well adapted to cooler temperatures, and the short growth period of the crop permits fitting them into cropping systems to utilize cool, moist seasons, between other warm-season major crops. The crop is grown as a winter annual in the Mediterranean region where it is planted soon after fall rains begin, and ripens during the following spring.

This general relationship extends across the Near East through Iran into Pakistan and India. Although planting is timed to precede the onset of rains, the crop usually ripens before high temperatures occur. In the tropics, lentils are grown at higher elevations, where there is a cooler season at the time of seasonal rainfall. Ethiopia and East African highlands, northern Mexico, and the Andean countries provide these conditions. Lentils do not tolerate heat and drought, and yields are severely depressed when these occur during the growing season.

Soils

Lentils prefer soils of moderate depth, generally good fertility, well-drained, and free of salinity. The crop grows on a wide range of soil textures, when carefully managed. It responds to use of mineral fertilizers, but not to nitrogen fertilizers. The effective methods of using fertilizers are not well understood; the broadcasting of fertilizers either before or after planting produces little benefit. As with most legume crops, improved cultural practices will produce more favorable growth conditions for lentils and subsequently increased yield of grain.

Description

Although there are substantial variations between varieties, the lentil is a short-season, erect, bushy, annual, herbaceous plant, that grows 25 to 75 cm tall. The stem is branched with pinnate leaves, having 4 to 7 pairs of leaflets, the leaf ending in a short tendril. The single or double flowers are borne on short stalks, and may be white, lilac, or pale blue. The pods are short, with 1 or 2 seeds. Seed coats of different strains and varieties may be green, reddish-green or brown in color. The seeds are typically lens shaped; the larger types are greater than 7 mm in diameter, while the smaller seeded types may be as small as 2 mm in diameter, and varying from 13,000 to approximately 50,000 seeds per kilo. The growing season for individual strains may vary from 70 days to 110 days, from planting to maturity.

Lentils have a branched tap root system, that penetrates 3/4 to 1½ meters into the soil. Under favorable conditions, the roots are well nodulated; the nodules being produced by lentil-type specific bacteria that fix nitrogen in forms utilized directly by the lentil plant. If the crop has not previously been grown on individual fields, the seed should be inoculated with fresh cultures of lentil root nodule bacteria, just before planting.

Varieties

Extensive collections of local and regional types of lentils (several thousands) have been made throughout the major lentil growing regions of the Mediterranean, the Near East, Asia, and Ethiopia. Seed of these, as well as of the improved selections, are available in the research institutions in Iran and India, and at the U.S. Department of Agriculture Plant Introduction Station at Pullman, Washington, USA. Certain selections have also been made available to research institutions in a number of countries.

To date, the selections made seem to have regional adaptation, rather than being generally more productive in all ecological zones. The superior performance of selections depends on climatic and soil adaptation, and resistance to specific diseases and insect pests. However, length of growing season, growth habit and size, seed characteristics, and non-shattering traits are universally expressed.

Since lentils are self-pollinated, the seed from individual strains breed true. Therefore, the increase of genetically pure seed is easy to achieve. The specifically desired traits from different selections may be combined by controlled hybridization. The hybrid populations are grown at least five generations, when the bulk hybrid breeding method is used, plants are then selected for desired combinations of traits. When the pedigree breeding method is used, selection of plants begins as early as the F_2 generation and continues in subsequent generations until uniformity is achieved. Since plant breeding is time consuming, full use should be made of promising selections made in other regions having similar ecological conditions.

Culture

Fertilization

There is very limited realization that lentils respond strongly to mineral fertilizers. The soils of the tropics and subtropics are characteristically rather deficient in mineral nutrients, but responses to fertilizers carrying these may be vitiated by failure to apply them in a manner that ensures their availability to the crop. Lentils respond to phosphate fertilizers rather strongly, to potash on certain soils only, and almost never to nitrogen fertilizers.

The phosphate should be placed in bands about 5 cm below the seed, so that the seedling roots will have ready access to it, but allowing only limited contact between phosphate and soil which causes conversion to unavailable forms.

Lentils also have substantial requirements for calcium, magnesium and sulfur. When ordinary superphosphate is used as a fertilizer, these other elements are provided in adequate amounts as well as phosphate. However, when concentrated superphosphate is used, it supplies phosphate largely, and is deficient in sulfur which must be supplied by other means.

Dung has been a traditional fertilizer, and it has values beyond those of chemical fertilizers. The phosphate contained is highly available, and dung carries other minerals as well. Broadcasting dung is a less effective use than placing it in shallow furrows below the seed. Opening a shallow furrow, spreading the dung, and covering it with 5-10 cm of soil, then placing the seed, and covering it with 2-3 cm of soil, will permit maximum benefits from dung. Superphosphate may be spread with the dung.

There is fragmentary evidence that "trace" element deficiencies occur on many tropical and subtropical soils. The elements are manganese, iron, copper, zinc, boron, and molybdenum. The specific deficiencies doubtless vary with soil type, and research is needed to identify the deficient element(s) in any region, so that appropriate treatments can be made. For the present, the use of dung is recommended as a natural product carrying small amounts of the trace elements in an available form. In some limited tests, rather pronounced yield increases have been produced by adding "trace" elements as well as fertilizers.

Seed Bed Preparation

The seed bed should be free of large clods, trash and growing weeds, relatively firm, and moist to the expected depth of the root system.

Planting

Broadcast planting is normally not recommended. Row planting permits proper placement of fertilizer, and it facilitates weed control and application of any insecticides needed. Rows may be spaced 60 cm apart, with seeding rates to produce 1 plant per 10 cm of row or less, using closer spacings for smaller varieties. Since the germination is hypogeal (the cotyledons remaining in the soil, and only the growing sprout pushing to the surface), soil crusting will be a detriment to a full stand of plants. Planting should be made in moist soil to foster prompt germination. Hard seed may be responsible for poor germination and emergence. Seed should be treated before planting to kill any maggots or weevils in the seed.

No specific recommendations are made for treating seed before planting since such treatments must follow in-country regulations.

Weed Control

Lentils are not strongly competitive with weeds, and failure to control weeds will seriously reduce yields. Weeds should be killed while still small, before serious damage has been done to the crop. Care should be taken not to injure the crop root system, whether weed control is by pulling, hoeing, or use of herbicides.

It is important that sowing seed be free of *Vicia* species; especially *V. sativa* var. *platysperma* which is nearly identical in plant and seed characteristics as common lentils and is somewhat a problem in some lentil growing areas.

Disease Control

Diseases of lentil are often an important factor limiting yields and reducing seed quality. Several diseases caused by fungi, bacteria, viruses, and nematodes affect the seeds, pods, foliage and roots of lentils. Little research has been done on the pathogens causing these diseases or on their control by use of resistant varieties, chemical methods or cultural practices.

Lentil varieties resistant to some diseases, e.g. root rot, rust and viruses, have been developed in a few countries, like India and Iran. However, lentil varieties resistant to diseases in one country or region may not be resistant to these same diseases in other areas due to differences in the microorganisms causing the diseases, weather conditions, soil and other factors. This emphasizes the importance of developing disease-resistant lentils in the regions where particular diseases are prevalent and of importance. It is also important to plant seeds that are free of diseases, since some lentil pathogens are carried by seed. Lentils should not be grown repeatedly on the same land since some of the soil-borne diseases which affect this crop survive for several years in the soil. With repeated cropping, these pathogens often multiply to levels which cause large crop losses.

No recommendations are made for treating seed before planting since seed treatments must follow in-country regulations. Seed treatment is nevertheless very important for the control of pathogenic fungi and bacteria on the seed surface and in the soil. Treated seed should never be used for livestock or human food.

Harvest

The ripening process should be allowed to continue in the field until the grain is fully dry. The moisture content should not exceed 10% for safe storage of the seed without molding. This stage of dryness is more easily achieved in the field than elsewhere. If earlier harvest is made to avoid shattering losses of grain, final sun-drying should be carried out on hard surfaces so that grain can be easily salvaged.

Threshing

Threshing may be done by hand flailing or by machines. Machine threshing is quite feasible, if proper adjustments are made to avoid splitting or cracking the seeds. All trash and foreign matter should be removed before placing the grain in storage.

Storage Insect Pest Control

Protection against storage insect damage requires immediate treatment after threshing. Empty storage structures and containers should be treated with malathion or other effective insecticides to kill all insects harbored in them. However, the grain must not be treated with poisonous insecticides. Instead, the lentil crop should be fumigated with appropriate fumigants when placed in storage, and treated again whenever any signs of reinfestation occur. For further details, see the Chapter on Maize, section on control of storage insect pests.

CHAPTER 15

BROADBEANS 1/

(*Vicia faba*) 2/

Other Common Names: 1/ horsebean, windsor bean, field bean, fava (or faba) bean, tick (or tic) bean, dhal, mazagan, fool (Arabic).

Description

The broadbean is a hardy, erect, simple-stemmed annual without tendrils, ranging from 30 to 190 cm in height and with one or more basal branches. It is very leafy with each leaf having from 1 to 3 pairs of smooth leaflets. The flowers, 2 to 6 in number, are borne in the leaf axils and are usually dull white in color with purplish lines on the standard, and dark patches on the wing petals. The pods are large and thick ranging from 4 to 30 cm in length and generally with 2 to 6 seeds per pod. A great variation occurs in seed size, with a range of 1,100 to 6,500 seeds per kilo, and the color may be light buff, brown, green, purplish or black.

The plant has a tap root system with many lateral branches, but has only moderate soil occupation considering the robust nature of the top growth.

Geographical Distribution

Broadbeans are a cool-season food grain legume, grown in the winter period in subtropical regions and at high elevations in the tropics. In temperate regions they may be either winter or spring planted depending on the variety.

1/ Edited by G. C. Hawtin, The Arid Lands Agricultural Development Program (ALAD), Beirut, Lebanon; D. A. Bond; Plant Breeding Institute, Maris Lane, Trumpington, Cambridge CB2 2LQ, England; and Ali E. Kambal and M. O. Khidir, Faculty of Agriculture, Khartoum University, Shambat, Sudan.

2/ *Vicia faba* is frequently divided into subspecies with some common names being limited to a particular subspecies.

Countries with the greatest production include Egypt, Ethiopia, Morocco, Tunisia, Turkey, Brazil, Ecuador, Peru and Mexico. Production is substantial also in Italy, Spain, the Peoples Republic of China and the United Kingdom.

National yield averages range from 330 to over 2,000 kg per hectare and large variations occur within individual countries. Undoubtedly, part of this wide range is due to the suitability of the climate for the species but much may be credited to differences in the application of available science and technology to the culture of the crop. The results from many field experiments indicate that yields may be increased several fold by growing improved strains with suitable cultural practices. Broadbeans, however, have received far less research attention in the tropics than have the cereal grains, but with the current growing interest in grain legumes this situation may soon be remedied.

Food Value

The broadbean is a very valuable source of plant protein and is of considerable importance in the diets of many people in the tropics and subtropics, where it supplements or "extends" the often limited supplies of animal protein. Broadbeans average 25% protein, 58% carbohydrates, 1.5 to 2.0% fats and about 3% minerals. The protein is somewhat deficient in the two essential amino acids - methionine and cystine but it is relatively rich in lysine which is characteristically deficient in cereal grains. Since cereals are well supplied with methionine and cystine, a combination of cereal foods with broadbeans or comparable food grain legumes, provides a more desirable amino acid balance in the diet than can be attained with cereals alone. Since broadbeans are also rich in carbohydrates, easily cooked, and high in digestibility, they warrant an important role in agriculture in those regions in which the crop is adapted. In addition, broadbeans are rich in the minerals calcium and phosphorus, and are generally higher in vitamin content than the cereals, which add to their value in human diets.

Although many of the toxic substances found in other *Vicia* species, (e.g. the cyanogenic glycoside, vicianin) are either absent, or present in only very small concentrations in broadbeans, low levels of certain tripsin inhibitors have been identified. It has been found that in general animal feeds should not contain more than 30 percent of the bean.

Broadbeans are known to cause favism or vicism, a disease characterized by hemolytic anemia, in certain individuals in countries surrounding the Mediterranean. Susceptibility is believed to be of genetic origin.

Utilization

Broadbeans are grown both as green shell beans and as dry beans for human consumption. The dry beans may also be used for feeding to animals including ruminants, pigs, poultry and even fish. The whole plant is sometimes made into silage, but it is rarely used as a hay or straw since on drying the stems and leaves tend to become rather hard.

The broadbean is regarded as a soil improving crop, primarily because of the increased residual nitrogen content of the soil left by this legume. The roots of the broadbean, in common with most legumes, produce a large number of nodules if they are inoculated with the right strain of Rhizobium root nodule bacteria. The plant not only receives all of the nitrogen compounds needed for growth from these nodules, but also large amounts of unused nitrogen compounds may be left in the soil. If the bean tops are not removed, their addition to the soil also contributes nitrogen and organic mater. The improved soil fertility following a crop of broadbeans will often reduce the need for nitrogen fertilizer in the succeeding crop.

Broadbeans have generally not been accorded a role as a major crop in farming systems, due in part to low and unstable yields in comparison with the cereals. It is now evident that yields may be greatly increased by the application of existing knowledge and this should enhance both the gross and net returns from the crop. The dry grain holds a strong position in food markets generally, and if higher yields and net returns are achieved, it can be expected that an increasingly important part will be played by this crop in the future.

The following discussions deal with enhanced production requirements.

Adaptation

Climate

Broadbeans are sensitive to high temperatures, particularly at a blooming time, which cause dropping of blossoms and failure to set seed. High temperatures can also induce severe disease problems. The crop thrives in the cool weather typical of winter and spring months in the subtropics, and responds to moderate rainfall (or irrigation). It grows well at higher elevations in the true tropics, if planted at the beginning of the cooler season when the rains arrive. The crop of beans should be well developed before moisture supply is exhausted, but drier weather is favorable during the final stages of seed development and ripening. Successful broadbean production requires careful adjustment of culture to climatic conditions.

Soils

The crop prefers soils of moderate to good fertility, well drained, and medium in texture. It is moderately salt resistant, which is a desirable trait in most regions of limited rainfall. A high percentage of tropical soils are deficient in mineral elements but the responses of broadbeans when such deficiencies are corrected has been poorly explored. By analogy with other legumes, however, it is expected that there is a good potential to be exploited.

Varieties

Collections of regional types, races, and named varieties have been made by several research institutions, including Karaj College in Iran. These collections together with certain selections made within them are grown by the U.S. Department of Agriculture at Puerto Rico. Research stations in Europe and Canada have collections of types and varieties adapted to those countries. Although the limited collections made to date show great diversity in plant and seed characteristics as well as yield and adaptation, the full potential of the species is believed to be much greater than revealed by the present collections.

Field evaluations of these collections have shown as much as a 4-fold increase in grain yield of certain types as compared with others from the same region under comparable cultural practices. The higher yielding lines averaged 4,000 kg/ha in some tests, compared to an average yield of 1,000 kg/ha and it is apparent that yield potentials have not yet been fully exploited. Some part of the great differences in yield may be attributed to varietal differences in resistance to plant diseases.

Culture

Rotation

Broadbeans should not follow any kind of beans in rotation but fit well both following and preceding a cereal grain crop. Such a rotation would help to control nematodes and diseases, facilitate weed control and provide a source of nitrogen for the cereal crop.

Fertilization

Nitrogen fertilizers are not generally required for broadbean production; however, applications of from 10 to 30 kg per hectare of nitrogen are sometimes applied as "nitrogen starters". Broadbeans have been shown to be responsive to phosphate fertilizers when effectively positioned in the soil, even though there is little response when such fertilizers are broadcast or mixed with the surface soil. The most effective method of supplying phosphate is in bands placed below and about 7 cm to the side of the row before planting. Animal manures may be similarly placed. An effective procedure is to place fertilizer and/or dung in a shallow furrow, cover with 5 cm of soil, place seed, and then cover with 3 to 5 cm of soil. This placement of phosphate avoids the interaction with soil that renders phosphate unavailable, and insures prompt access to phosphate by the developing root system. Potash is rarely deficient in soils of regions with limited rainfall and on soils that have not had a long history of cropping, but if needed it may be applied with the phosphate.

The value of manure seems to be related to the high availability of the phosphate it contains, but other real benefits have not been well explored. Since some tropical and subtropical soils have been shown to be deficient in "trace" elements (manganese, iron, zinc, copper, boron, and molybdenum), and animal manures carry small amounts of these in a readily available form, the responses from manure may be attributed in part to correction of trace element deficiencies.

Fertilizer needs should be determined by well designed field trials. In the absence of such trials, the application of superphosphate at rates of 50 to 100 kg/ha of P_2O_5 may be used. If potash is deficient, this may be applied at rates to deliver 25 to 50 kg/ha of K_2O. Trials in temperate regions on soils that have been farmed for many years suggest the possible need for potassium.

Seed Bed Preparation

Land should be prepared for planting by killing all weeds present, removal or turning under all coarse trash, and breaking up of any coarse clods. Fertilizer should be positioned below the seed before planting.

Planting

Broadcast planting is not recommended. The crop should be planted in rows 75 to 100 cm apart and seeded to provide one plant per 15 to 25 cm of row. The closer spacing is preferred for varieties with small growth habits. Such spacing will require 70 to 100 kg/ha, depending on varietal seed size. Depth of planting should be such as to place seed in moist soil, but no deeper than 5 cm to avoid poor emergence should soil crusts develop as a result of heavy rains followed by rapid drying. If simazin pre-emergence spray is to be used, the seed should be covered to a depth of 7 cm.

Planting seed should be treated to control insects when put in storage and again before planting if weevils are suspected to be within the seed. It is probable that weevils within the seed bulk but not inside the grain will be *Sitona* spp. and those in holes within the grain will be the beetle *Bruchus*. Suitable seed should have 80% or greater viability. Treating the seed with a protectant before planting should be carefully limited to that seed which is to be planted immediately since such treatments are poisonous to man if the seed is eaten. The in-country regulations must, or course be followed.

Weed Control

Weed control is necessary for higher yields. Early weed removal is important, to remove weeds before they damage the crop's root system by competition. If pulling, hoeing or other tillage cannot be completed in timely fashion, herbicides may be used to kill weeds without disturbing the broadbean root system. Good weed control has been obtained by the use of simazine as a pre-emergence spray. If this chemical is used, the seed should be covered with at least 7 cm of soil and this should not be disturbed after spraying.

In many regions the parasitic weed broomrape (*Orobanche* spp.) can cause very extensive damage and in some countries, e.g., Egypt, it constitutes a factor of major importance in limiting yield. At present, no completely effective herbicides have been found, although certain trials have indicated that the chemical "eptam" may give a useful measure of control. On land which is very badly infested it may be necessary to stop broadbean production for several years.

Disease Control

There are a number of fungal diseases which may cause extensive damage to crops of broadbeans in tropical and subtropical regions. These diseases include chocolate spot (*Botrytis fabae* and *Botrytis cinerea*) broadbean rust (*Uromyces fabae*), leafspot, also known as blight or anthracnose, (*Ascochyta fabae*), powdery mildew (*Erysiphe polygoni*), and the root rots (*Fusarium* spp. and *Rhizoctonia* spp.).

The most important control measures are: (1) planting varieties which are resistant to the diseases commonly present in the regions, (2) field sanitation and (3) using suitable agronomic practices. Field sanitation consists of such things as crop rotation, so that broadbeans are not grown on the same land in successive years and removal of all crop residues after grain harvest. These measures reduce the disease inoculum present when the next crop of broadbeans is grown. Agronomic practices which are important in disease control include the use of wide rows to help prevent disease spread, a date of planting which minimizes infection and development of the disease, and the maintainance of suitable soil moisture levels through the use of irrigation and drainage. Chemical control has been shown to be effective in several cases, e.g., chocolate spot can be controlled by the use of benomyl or dithane M.45 and leaf spot can be effectively controlled by seed treatments.

In addition to the fungal diseases, the broadbean is susceptible to a number of viruses including broadbean mosaic virus (BBMV), bean yellow mosaic virus (BYMV), pea leaf roll virus (PLRV) and alfalfa mosaic virus (AMV). Little resistance to these viruses has been found, and the best control is achieved through spraying or agronomic practices to reduce the aphid vector populations.

Insect Pest Control

Broadbeans may be attacked by various insects that can cause serious damage. These include aphids, thrips, weevils, and cutworms. If possible varieties should be planted that are resistant to important local insects. Crop rotation is an asset, but it may be necessary to combat infestations by application of insecticides. Sitoma is often present and can be controlled with BHC, but damage rarely warrants it. *Aphis fabae* can be devastating and must be controlled by systemic sprays or they can be quickly knocked down with demeton-S-methyl (not dimethoate because of danger to bees). Slow, but persistant control can also be obtained with menazon and preventative and persistent control can be obtained with granules of disulfoton or phorate. All insecticides should be applied according to manufacturer's recommendations. Timing is important and should be applied if possible when application machinery will do a minimum of damage to the crop.

In any spray program bees should be protected and if none are present they should be introduced, especially in open type landscapes where there are few nesting places for bumble bees. Apart from their help in tripping the flower petals, the bees can cause up to 30 or 40% outcrossing which helps maintain a degree of heterozygosity in the population. Although some varieties, especially the small seeded ones are more autofertile than others, the chances of a good seed crop are better with pollinating insects present, and a crop that is partly cross-fertilized should provide better yields in the next generation than one that is completely self-fertilized.

For further information on Crop Protection, see Chapter 4 in book on "Tropical Agriculture", by Wrigley (Reference list following Chapter 40).

Harvest

The beans are fully formed when the pods begin to turn color, but seeds should dry down to about 10% moisture for safe storage. Field drying on the standing plant is the most effective method, unless the variety tends to lose seed by shattering as the pods dry out. Most varieties, however, should be harvested while some pods are black and some are still green and allowed to ripen after cutting.

Threshing

Broadbean seeds are large, and threshing practices should be adjusted to avoid cracking or splitting of the beans. Hand flailing is common but broadbeans can be combined direct provided the crop is ripe and dry, concaves are set wide (according to seed size), drum speed is slow (about 650 r.p.m.) and with full airflow, fast forward speeds and proper size sieves.

Control of Storage Insects

In common with other legume seeds, broadbeans may suffer severe and rapid damage in storage unless immediate treatment is given. The danger of infestations from insects harbored by empty storage structures or containers may be avoided by treating these with malathion or other suitable insecticides. The grain should be fumigated at the time it enters storage to kill insects carried from the field. In the event of later infestations, additional fumigation may be needed.

CHAPTER 16

MUNGBEANS [1/]

(*Vigna radiata*)
(Formerly, *Phaseolus aureus* and *P. radiata*)

Other Common Names: green gram, golden gram
moong, mongo, mung

Distribution and Utilization

Mungbeans are grown widely in the southern half of Asia, including India, Burma, Thailand and the Philippines. They are grown to a lesser extent in many parts of Africa and in the tropical Americas. They are grown in Oklahoma in the U.S.A. Mungbeans are grown widely as human food (dry beans and sprouts), but also may be used for green manure (soil improvement), and as forage for livestock. They are frequently grown as a secondary crop in rotation with rice, or cotton, or wheat, or corn.

Mungbeans are high in protein--24%--and are useful in human diets to supplement cereal grains and other starchy foods. The protein is somewhat deficient in two amino acids --methionine and cystine--but well supplied with lysine and tryptophan in which cereals are deficient. Cereals are higher in methionine and cystine, so that the two classes of crops are supplementary in terms of balancing the dietary amino acid content. Mungbeans are used as a supplement for scarce animal proteins in the tropics and subtropics. Mungbeans average high in carbohydrates (58%) making them a nutritious foodstuff. They are easily digested and reputed to be low in flatulence. They are well supplied with calcium and phosphorus, as well as with vitamins, adding to their importance in human diets.

Adaptation

Mungbeans are best adapted to warm climates. The crop is often grown with limited rainfall, by utilizing residual moisture in the soil profile after an irrigated crop (rice, cotton), or as a main crop in a region with a short rainy season. When grown in a prolonged rainy season, the vegetative growth tends to be excessive, the plants may be broken over by heavy winds or rainstorms, and seeds may germinate or mold in the pods. Mungbeans are responsive to changes in

[1/] Edited by J.M. Poehlman, Professor of Agronomy, Department of Agronomy, College of Agriculture, University of Missouri, Columbia, Missouri 65201 length of the daylight period. They flower quickly when grown in the short days and higher temperatures of the tropics but flowering may be delayed in long photoperiods at high latitudes. Varieties differ in their photoperiod response.

Mungbeans are adapted to fairly deep and fertile soils. Soil depth is important from the standpoint of the moisture that may be stored in the soil profile. Soil fertility does not include the nitrogen-supplying power of the soil, since the mungbean is a legume, capable of supplying its nitrogen needs independently of soil or fertilizer nitrogen when supplied with proper cultures of Rhizobium. Mungbeans have a high requirement for mineral nutrients (phosphorus, potassium, calcium, magnesium, and sulfur), and higher yields are produced on soils capable of meeting the crop's requirements.

Description

The mungbean is a member of the legume family. It is a warm-season annual, with different varieties growing 30 to 60 cm tall, with an erect but spreading habit of growth. It has trifoliate leaves resembling those of cowpeas, except they are prominently hairy. Yellow flowers are borne in clusters on peduncles of variable length; pods are neatly cylindrical, 4 to 10 cm long, hairy to smooth, carrying 8 to 12 seeds per pod. Seeds are roundish to square on the ends, and generally are smaller than most food grain legumes --20,000 to 25,000 per kilo. Seed colors of types and varieties are usually green but may be brown to golden. Germination is epigeal with cotyledons and shoot pushing through the seed bed.

The mungbean has a tap root, comparatively well-branched and extensive, thus permitting exploitation of soil moisture to considerable depths. The drought resistant reputation of the crop is partially justified by reason of the well developed root system, and partially by certain varieties having short life periods (as short as 45 days) which permits them to mature before soil moisture is exhausted.

Varieties

A large collection of types and varieties are maintained by the United States Department of Agriculture at the Regional Plant Introduction Station, Experiment, Georgia. Most of these came from the Indian subcontinent but collections have recently been added from Korea, Thailand, the Philippines, and other sources. The varieties and types in current collections show a wide range in plant types and growth habit, in resistance to disease and insect pests, as well as in yielding potential. Plant height of different varieties varies from 30 to 60 cm, and life period from 50 to 120 days depending upon the photoperiods and temperatures where they are grown. A very wide range in yields of the different strains growing at the same location in the same season may be obtained with maximum yields of 2500 to 2800 kg/ha having been reported under the most favorable environmental conditions.

Mungbeans are self-pollinated, and selections will breed true except for occasional mutations or natural hybrids. Very little purposeful breeding research on mungbeans has been carried out in many of the countries where the crop is currently grown. Breeding programs are now in progress at Karaj, Iran; at Ludhiana (Punjab), Delhi, and other locations in India; at Los Banos, Philippines; and Stillwater, Oklahoma, U.S.A. An extensive breeding program is being initiated at the Asian Vegetable Research and Development Center, Tainan, Taiwan (Republic of China).

The First International Mungbean Nursery was developed in 1972. The nursery is coordinated by the University of Missouri, Columbia, Missouri, U.S.A., in cooperation with USAID. Evaluation of the genetic potential of the mungbeans, studies on the photoperiod sensitivity in relation to varietal adaptation, and research on other problems are also in progress at the University of Missouri.

Multiplication and distribution of improved varieties should be easily accomplished, and growers may save their own seed without loss of heritable traits.

Culture

Fertilization

Being a legume, mungbeans do not generally need nitrogen fertilizers. Their nitrogen needs are met by nitrogen fixation in the plant root nodules, which provide the plant with all of the necessary nitrogen. In areas where mungbeans have been grown for long periods, nitrogen fixing bacteria may be present in the soil already, making artificial inoculation of the soil unnecessary. In new areas, where the crop has not been grown before, the seed should be inoculated before planting with a suitable culture of the *Rhizobium* organism.

The mungbean crop has a relatively high requirement for mineral nutrients. The significant feature is that of proper placement of mineral fertilizers so that the nutrients are actually available to crop roots and are not inactivated by interaction with the soil. This is achieved by positioning the fertilizer in the soil, in bands placed below the seed. Broadcasting mineral fertilizers and mixing these through the whole soil mass are unlikely to be beneficial because of reaction of the phosphate with soils to form insoluble and inert compounds.

A practical method for positioning mineral fertilizers is to open a shallow furrow, spread the fertilizer as a band in the furrow, cover with about 5 cm of soil, place seed thereon, and cover seed with 2 to 3 cm of additional soil. If ordinary superphosphate is used, this will carry calcium, magnesium, and sulfur as well as phosphorus. However, if concentrated superphosphate is used, it will contain little sulfur, and this element must be provided by other means. Some soils also are deficient in potassium, and if this be so, it is desirable to add a mixture of superphosphate and potash. If field trials have not been made to determine fertilizer needs, it is suggested that phosphate fertilizer be added to supply about 50 kg/ha of P_2O_5, plus potash fertilizer to supply 25 kg/ha of K_2O. The pH should be around neutral.

There is limited but strongly suggestive evidence that many tropical and subtropical soils also are deficient in the "trace" elements; manganese, iron, copper, zinc, boron, and molybdenum. Until the specific deficiencies of soil areas are more definitely known, it may be useful to adopt the practice of spreading animal manures, jointly with phosphate fertilizer, as a source of trace elements. The trace element content of dung is small but it may be sufficient to permit responses of the crop to mineral fertilizers. The amount of dung required to make a band placement with the superphosphate is quite modest, and that is an efficient use of limited supplies of dung.

Seed Bed Preparation

Where feasible, the seed bed for mungbeans should have all plant growth killed, trash removed or covered, and large clods broken up. The goal also is to provide a seed bed that is moist to considerable depth, using those practices that will avoid rainfall runoff, and foster moisture storage in the soil profile.

Planting

Row planting is recommended, in rows about 50 cm apart. Seed should be placed to produce one plant every 4 to 5 cm of row. Since seeds are small, they must not be planted too deeply, to avoid impedance of seedling emergence that may occur with soil crusting. Planting in warm, moist soil will hasten germination and seedling development. (NOTE: No recommendations are made on treating seed before planting, since such treatments are poisonous to man if surplus seed is eaten. Seed treatment must follow in-country regulations.)

Weed Control

Mungbeans are not strongly competitive with weeds, and therefore weed control is important. Weeds should be removed while still small, to avoid injury to the mungbean root system. Weed control by pulling, hoeing, or tillage may be damaging, and will reduce yields if not done early. Pre-emergence herbicides, such as chloramben and trifluralin, may be used to control small seeded broadleaf and grass-type weeds. Spot application of herbicides may be used to kill weeds where they have reached such a size that pulling or tillage could be harmful. Care must be taken not to get the herbicide on the mungbean plant. Strict adherence to the directions for application of a specific herbicide should be followed as well as the in-country regulations.

Disease Control

The diseases of mungbean most common are the viral diseases, mildew, and *Cercospora* leaf spot. Information on their prevalence and control is scanty. Most widespread viral disease appears to be the mungbean leaf crinkle virus. It may be identified by rolling or puckering of the leaf, dwarfing of plants, abortion of flowers, and reduction in pod number and size. Vectors and host range are not well known. In Pakistan, India and other areas, the bean yellow mosaic virus is a serious disease. It is reported to be spread by a species of whitefly, *Bemisia tabaci*. *Cercospora* leaf spot produces a brown spot on the leaf, often with a small lighter colored spot in the center. Mildew produces a white mycelial growth which covers the leaf surface.

Definitive control measures for mungbean diseases are not available. In India, bean yellow mosaic virus damage may be reduced by planting in seasons when the vector population is low. Disease damage may be minimized by practicing field sanitation to reduce the amount of inoculum that may infect the crop. Field sanitation includes rotation of crops so that mungbeans are not grown on the same field in successive years, and removal of crop residues after harvest. The latter make good forage for livestock. Varieties differ in resistance to these diseases and these may ultimately provide the best disease control. Currently, recommendations for disease resistant varieties of mungbeans are not available. Oftentimes, local varieties and local practices may have evolved which will avoid serious losses from diseases.

Insect Pest Control

As with diseases, information on the insects that injure the mungbean plant and the control of these insects is not well known. Some insect pests known to be harmful to mungbeans are the bean shoot fly, plant hoppers, pod worms, aphids, leaf rollers, blister beetles, stink bugs, and seed weevils. In the Southeast Asia area, the bean shoot fly appears to be the most damaging insect. The eggs are laid on seedling plants at or near ground level and the larvae bores down through the stem, pupating in the root. This feeding habit kills the seedling plant. Stands may be reduced by as much as 80 to 90 percent by this insect pest.

Control measures include (1) field sanitation, (2) use of insecticides, (3) planting during months when the insect population is lowest, and (4) in case of the bean shoot fly, planting at an excessive rate and thinning to a normal stand after the damage has occurred. Field sanitation operates to reduce the number of insects at the beginning of the growing season. The grower should remove all crop residues as soon as the mungbean crop has been harvested and should practice crop rotation. Despite preventive measures some insects may increase to become a menace. These should be attacked promptly with appropriate insecticides effective on the species at hand. Early treatment will prevent the insect from becoming an economically destructive pest. Systemic insecticides, such as dimethylate, or furadon, applied at the time of planting, are helpful in controlling the bean shoot fly. Recommendations for insect resistant varieties are not available, although, as with diseases, locally productive varieties may possess some resistance to the local insects, and local practices may have emerged which reduce injury to the crop.

For further information on Crop Protection, see Chapter 4 in book "Tropical Agriculture" by Wrigley, (Reference list following chapter 40).

Harvest

In most tropical countries, mungbeans are harvested by hand picking. The mungbeans are generally picked in two flushes since the flowering is indeterminate and the pods may set and ripen over a period of several weeks. In the irrigated tropics, flowering may be terminated and the plants brought to maturity by withholding irrigation. After picking, the pods should be allowed to ripen and dry in the sun until the moisture content drops to about 10 percent. This is necessary for safe storage without molding. Some varieties tend to shatter if left in the field after ripening, or the seeds may germinate in the pod during prolonged rainy periods. In the U.S.A., the mungbeans are harvested with a combine-thresher.

Threshing

Mungbeans thresh easily; hand flailing is effective, but machine threshing is practical if suitable threshers are available and proper adjustments of the machine are made to avoid splitting or cracking the seeds.

Storage Insect Pest Control

All seeds and grain require treatment in warm climates to protect against serious insect damage and losses. All empty storage structures and containers should be treated with malathion or another equally effective insecticide before filling to destroy insects they may harbor. However, the beans should be fumigated before placement in storage to kill insects brought in from the field. The stored beans should be inspected periodically to detect any subsequent infestations, and treated promptly if they occur. For further details on fumigation, see the Chapter on Maize, section on storage insect pest control. In hot dry seasons, the threshed seeds may be spread out in the sun to reduce the insect infestations.

URDBEANS

(*Vigna mungo*)

Other Common Names: black gram, mash, urd, urid

Urdbeans are closely related to mungbeans and are similar to mungbeans in plant characteristics, cultivation, and utilization. Flowers are normally deeper yellow than mungbeans. Seeds of urdbeans are usually smaller than seeds of mungbeans and normally black in color with a raised, white concave hilum. The pods are shorter and more hairy and are held erect as opposed to the drooping habit of the pods of mungbeans. Cultivation practices, in general, do not differ from those of mungbeans. Production of urdbean is not as extensive as for the mungbean. Specific varieties have been developed and are cultivated in India and other countries. As with mungbeans information on disease and insect pests and measures to control them is scarce.

CHAPTER 17

PIGEON PEA [1/]
(*Cajanus cajan*)

Other Common Names: Congo bean, Angola pea, red gram, yellow dhal, alberga, tur, arhar.

Geographic Distribution

Pigeon peas are grown widely in the tropics and sub-tropics, where they are harvested as grain, or as a green vegetable, and as fodder to feed livestock. The reported principal world production occurs in India and Burma in South Asia, Uganda and Malawi in Africa, and the Dominican Republic, Venezuela and Puerto Rico in Latin America. India produces nearly 91 per cent of the world's entire production of pigeon peas. Average grain yields per country range from a low of 310 kg/ha for Burma, to 1130 kg/ha in Puerto Rico. The world average is 670 kg/ha. However, yields of 3000 to 4000 kg/ha have been reported from specific fields in various regions.

The crop is handled in many ways in various regions; as long season (7-9 months) and medium duration crops of 5-6 months duration as warm season annuals. It is grown alone, or intercropped with sorghum, maize, groundnut, millet or cotton; grown as a short-lived perennial with successive hand-pickings, beginning at about 5 months; or as a terminal crop for 3 to 4 years before the land is returned to production of annual crops.

When grown as a perennial, the tops are cut back to about 30 cm after the first crop of pods is harvested, and second growth is made for another crop of pods and grain. However, yields decline steadily after the first crop, and are usually not economic. The best use of pigeon peas is to produce a single first crop.

Pigeon peas are grown widely as a subsistence food crop, and they enter domestic and export markets mostly in the countries listed above. The crop appears to have a unique place in agriculture because of its drought resistance, and its value as a cash crop when production exceeds family food needs.

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Pigeon Peas as a Foodstuff

The composition of pigeon peas is similar to the other food grain legumes; protein 22%, carbohydrate 60%, fats 1.5%, mineral matter 3.5%. The contents of calcium, phosphorus and iron are high, as well as the content of vitamins (except for ascorbic acid). Pigeon peas constitute a high-protein food, which serves to balance the extensive use of cereals and starchy foods in human diets in the tropics and subtropics. In comparison with animal products and fish, pigeon peas are deficient in two amino acids - methionine and cystine, but much higher in these than the cereal grains and starchy crops. In subsistence diets, pigeon peas (and other food grain legumes) are considered "extenders" of animal proteins.

When pigeon peas are harvested green (before ripening) as a foodstuff, they are easily cooked and have high digestibility. The dry pea may have a hard seed coat and is slower to cook than many other food grain legumes, but this appears to be a varietal trait, that may be associated with weather conditions during ripening. With the tremendous range of types (5000 accessions in recent collections) available for testing, it is probable that many rapidly cooking types will be found.

Adaptation

Climate

Pigeon peas are short-lived perennials, often grown as warm season annuals, that have wide adaptability and grow especially well in subhumid regions and regions with long dry seasons. Its drought tolerant trait is best expressed, however, where the soil permits deep and extensive rooting. As a species, pigeon peas bloom and produce seeds in the season when day length is shortening; such changes in day length being more noticeable in the subtropics with higher latitudes. However, some varieties are known to be insensitive to day lengths, and these are more useful in all tropical farming systems. The photosensitive varieties should be planted about 5 months before day lengths fall below 12 hours per day, to produce a crop of peas in 6 months from planting. Otherwise, the crop remains vegetative until shorter days occur. The crop is sensitive to frost (higher altitudes of subtropics).

Soil

Pigeon peas appear to be adapted to a wide range of soils, preferring soils that are well suited to growth of maize, sorghum and millet. Wet soils are unsuited, but the crop tolerates some alkali and salinity, frequently found in regions of limited rainfall. Among the food grain legumes, it appears to have a greater capacity to meet its mineral requirements on less fertile soils than other species.

Description

The pigeon pea may be described as a much-branched shrub, a short-lived perennial that may be grown as an annual, that grows 2 to 4 meters tall, depending on variety. The entire plant is pubescent, the leaves each have 3 long leaflets, and the flowers are borne in racemes in leaf axils. Flower color may be yellow or yellow red. The pods are 5 to 8 cm long, with 4 to 7 seeds per pod. There are about 18,000 seeds per kilo. The seeds are round, with one edge flattened, about ½ cm across, usually brown, with a white spot at the attachment to the pod.

This crop is largely self-pollinated, but 5 to 20% natural crossing in the field has been reported. As a result, there is considerable variability in plant type and other characteristics in most seed lots. Seed production handled so as to maintain variety or strain purity requires careful roguing of all "off-types" in the seed fields and isolation from other fields. Improved strains in the hands of farmers are likely to lose their identity rapidly if more than one variety is grown in a locality. There is some advantage possible with the variability usually present in unselected seed lots, since it permits continuing selection to produce strains that appear to have greater productivity under local conditions.

Varieties

There are many named varieties grown in the tropics and subtropics. They fall in two main divisions or groups: (1) the early yellow-flowered group, and (2) the later bicolor (yellow, brown, red, purple) group. However, the earliness or lateness may be associated with almost any other combination of plant size, flower color, seed color and productivity. Because of the appreciable amount of natural cross pollination, new combinations of traits are easily produced by selection of desirable types, following by growth in isolated fields and removal of all unwanted plants before blooming. For selection of high-yielding ability, pest resistance and desired grain characteristics, a portion of the seed of selected plants can be field tested, and the seed of the better performers may then be planted in seed multiplication fields. Continued selection for several plant generations, of segregating hybrid plant populations, is necessary to "fix" the heritability so that the strain will breed true.

At least 5000 accessions of pigeon peas were originally collected and grown at the Indian Agricultural Research Institute, covering a very wide range of types, varieties and selections. Such a collection offers opportunity to identify strains with specific ecological traits, desirable plant and seed characteristics, and yielding potential. If established varieties do not fulfill local needs, the great collection of accessions offers a fertile ground for searches to be made by growing many of these in field trials. The International Crops Research Institute for the Semi-Arid Tropics, Hyderabad, is the world centre for research on pigeon peas and it has most of the world germplasm collection.

Yielding capability in pigeon peas is usually associated with adaptation to local climate and soils, and resistance to pests. It appears feasible to increase present average yields by at least 3-fold, by growing adapted strains, and by following cultural practices suited to pigeon peas.

Culture

Fertilization

The pigeon pea has a reputation for being adapted to a wide range of soil conditions, as well as being drought tolerant. The wide soil adaptation has led to the belief that it can derive the necessary plant nutrients from comparatively less available forms of nutrients in the soil, in contrast to many other crops. However, it is probable that the unusually deep and extensive root systems that the pigeon pea develops during its growth period gives the crop access to minerals not reached by lesser root systems, but it also responds to fertilizers.

Being a legume, pigeon peas are not dependent on soil or fertilizer to meet its rather high nitrogen requirements. The crop has a high content of phosphorus, potassium, calcium, magnesium and sulfur. Undoubtedly, the augmentation of natural soil fertility with rational fertilization will enhance yielding ability, particularly for crops produced in 5 to 6 months. Field trials of responses to fertilizers should include their placement in bands below the seed to minimize inactivation by reaction with the soil, and to give growing plants early and continuing supplies of the mineral fertilizers during the growing season. Field trials are the most reliable guide as to fertilizer treatments that will enhance yields. If such results are not available it is recommended that initial trials apply ordinary superphosphate at a rate to supply 50 kg of P_2O_5 per hectare, and potash fertilizer to supply 25 kg of K_2O per hectare. Ordinary superphosphate also carries calcium, magnesium, and sulfur in sufficient amounts. However, if concentrated superphosphate is used, it does not contain sulfur and this must be supplied by other means on many soil types.

A practical method of positioning fertilizer to meet crop needs is to open a shallow furrow, spread the fertilizer, then cover it with soil to a depth of 5 to 8 cm, place the seed thereon, and cover it with about 3 cm of soil. Mixing mineral fertilizer through the soil mass, or broadcasting it, very often will show no benefits because of prompt transformations into insoluble forms that are less available to plant roots.

There is a strong probability that many tropical and subtropical soils are deficient in the micronutrients that are needed by legumes in very small amounts. These elements are manganese, iron, copper, zinc, boron, and molybdenum. Until field research is done to identify those micronutrients that may be short in supply (and prevent response to other fertilizers), animal manure may be used to provide small amounts of the trace elements. Where specific micronutrient deficiency is known, the salt containing the nutrient may be drilled along with the fertilizer. Dung may be spread with the superphosphate, where this is being applied by hand. If the dung is to be applied separately, it may be placed in the bottom of the plowed furrow, under the intended position of the plant row. Banded application of dung will maximize nutritional benefits and conserve the limited supplies usually available.

Seed Bed Preparation

For interplanting with maize, sorghum, or millet, preparation for planting pigeon peas need only to be altered to include proper positioning of fertilizer and/or dung under the plant row. All growing weeds should be killed, trash removed or turned under and large clods broken up. In drier climates, soil moisture conservation practices should be followed to store as much rainfall as feasible in the soil profile before planting.

Interplanting of shorter season cereals like pearl millet, sorghum, cotton with longer season pigeon peas may produce greater total yields than either crops grown alone, because of more complete utilization of soil moisture. However, where greater total yields, or crop values, are not achieved by interplanting, single cropping to pigeon peas is recommended using varieties that will ripen a crop in 5 to 6 months.

Planting

Single cropping with pigeon peas should provide planting in rows 50 to 100 cm apart, with seed spaced to provide 1 plant per 20 to 30 cm of row, for full use of the soil. This will require 15 to 25 kg of seed per hectare, depending on seed size of the variety planted. Seed should be planted in moist soil, at depth of 3 to 5 cm to permit prompt emergence. Deeper planting is undesirable, particularly on soils that tend to form crusts after rainfall. (NOTE: No recommendations are made on treating seed before planting, since such treatments are poisonous to man if surplus seed is eaten; and must follow the in-country regulations.)

Weed Control

Pigeon peas have a reputation for competing strongly with weeds, but this is true only with full stands, after the pigeon peas reach a height of about 1 meter. In early growth stages, weeds provide serious competition and retard development of the crop. Therefore, weed control is essential to higher yields under all conditions, particularly with limited rainfall. Weeds should be killed while still small to conserve moisture and nutrients, and to minimize physical damage to pigeon pea root systems from weed pulling or tillage.

Disease Control

Pigeon peas are attacked by a number of rootrots, and leaf and stem diseases. The two major preventive measures that are effective in controlling such diseases are: (1) planting of only disease resistant strains or varieties, and (2) practicing field sanitation. Field sanitation includes growing pigeon peas in rotation with other crops, so that pigeon peas are never grown on the same fields in successive years. Also, remove the entire top growth after grain harvest by feeding to livestock, or plowing under. These methods will greatly reduce the amount of disease inoculum present when the following crop of pigeon peas is planted.

Insect Control

In common with other legumes, pigeon peas may suffer severe insect pest attacks. These occurrences may be minimized in severity by (1) planting resistant strains or varieties, and (2) practicing field sanitation. After the crop is harvested, remove and feed all top growth to livestock; or cut it down and turn it under for soil improvement. These measures will greatly reduce insect populations at planting time, particularly if neighboring growers can be induced to take similar action.

Pod borer is a very serious pest which affects the crop badly. When serious infestations occur, they should be treated promptly with effective insecticides. Prompt treatment at the start of infestation is most effective. (See footnote.)

Harvest

Pigeon peas, being essentially perennials, do not flower, seed and ripen in a rapid sequence. However, some varieties and strains approach the desirable goal of single cropping. Usually, more than one picking of ripe pods is needed. Since the crop is harvested by successive pickings, it is necessary that they be carefully dried on a hard floor (to save shattered seed). Drying should continue until the grain drops to about 10% moisture, so that it can be stored without molding. Early harvest will reduce the tendency for hard seed coats that sometimes make cooking difficult.

Threshing

Well-dried pods may be threshed readily, by hand flailing, or by machine threshing with adjustments to avoid splitting or cracking the seed.

Protection against Storage Insects

Insect damage may be severe unless protective measures are invoked at the time of storage. All empty structures and containers should be treated with malathion or other

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Footnote: For further information on Crop Protection, see Chapter 4 in book on "Tropical Agriculture" by Wrigley, (Reference list following Chapter 40).

effective insecticides to kill insects harbored therein, before being filled with grain. As the crop enters storage, it should be fumigated to kill all insects brought in from the field. Periodic inspections thereafter should be made to detect any subsequent infestations, and fumigations made as needed. For further details, see the Chapter on Maize, section on storage insect pest control.

CHAPTER 18

FIELD PEAS (Including Garden Peas and Edible Podded Types) (*Pisum sativum*) [1/]

Geographical Distribution

Peas are characteristically grown as a cool-season annual. They are best suited to the winter period of the subtropics, and to the higher altitudes in the tropics. They are planted at the beginning of the rainy season in the tropics, which is comparatively cool. The crop probably originated in Ethiopia, from which it spread in prehistoric times to the Mediterranean region, and thence to Asia, and to the temperate zones throughout the world.

Production in the tropics and subtropics is most extensive in India and Burma, in Ethiopia, the countries bordering on Lake Victoria in East Africa, the Congo and Morocco, and in Colombia, Ecuador and Peru in South America. Average grain yields for these countries ranges from 920 kg/ha in the highlands of Ethiopia and Peru to 400 kg/ha in some other countries. However, the crop has a yield potential under favorable climate and culture at least 3- to 4-fold higher than the average yields reported. Outside of the temperate zone countries, the crop has received very little attention on breeding improved varieties.

Utilization

In the Mediterranean region, and the regions extending across the Near East to Mainland China, the crop is typically grown in the winters. Since peas will tolerate light frosts, they are suited to higher elevations in the subtropics, and are used as a winter crop in farming systems. Where rainfall is limited to the cool period, peas may constitute a major crop. They also are grown successfully under irrigation in cool seasons.

Peas As A Food

Dried peas constitute a major foodstuff in the markets of the tropics and subtropics; sold either as whole dry peas or split peas. The average composition is similar to that of other food grain legumes - protein 25%, carbohydrate

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59-60%, fat 1.0%, and minerals 3 to 3.5%. It is a high protein food; but in contrast to animal proteins, it is somewhat deficient in two amino acids - methionine and cystine. Peas are a valuable supplement to cereals and other starchy foods in the human diet, because of their high content of lysine and tryptophan in which cereals are deficient. Peas may be used as an "extender" of animal proteins that are usually in short supply in diets of people in the tropics and subtropics. Peas also are rich in calcium, phosphorus and iron, and in vitamins, except for ascorbic acid or vitamin C which can be obtained by germinating the seed. Peas are not only widely accepted as a nutritious foodstuff, but they constitute high-value cash crops for the growers who produce more than is needed for family subsistence.

Adaptation

Climate

Peas are best adapted to cool climates with moderate rainfall. They will survive light frosts without injury. Peas are grown in the winter period of subtropical zones, or in the cooler season of the true tropics which begins with the onset of the rainy season. However, the crop is most important at higher elevations in the true tropics, as shown by production in the Andean countries of South America, in East Africa, and in the Republic of Congo. Peas may produce well in seasons with limited rainfall, if the soil profile is moist. In such locations, the crop produces grain largely on this stored moisture.

Soil

Peas prefer soils that are not strongly acid, and that are moderately to well supplied with calcium. Soils derived from limestone are well-suited for peas. The crop is not well-suited to highly leached soils normally found in high rainfall areas of the tropics and subtropics. Although peas are not considered to be a deep rooted crop, they are not tolerant of shallow soils, nor those that are poorly drained.

Since the crop is rich in minerals, peas have high requirements for the major mineral nutrients - phosphorus, potassium, calcium, magnesium and sulfur. These nutrients are usually not naturally present in adequate amounts in many soils, and must be provided as fertilizers in the amounts needed to compensate for soil deficiencies. The problems of supplying mineral fertilizers in forms that peas can utilize are less difficult on soils described above, than on highly leached soils in high rainfall areas.

Description

Garden and canning peas are merely types within the species known as field peas. Peas belong to the legume family, and the nodulated roots supply nitrogen in forms suited to the plant, independently of soil nitrogen or nitrogen fertilizers. The pea is an annual, with climbing or half-bush growth habit, reaching heights of 1 to 2 meters (depending on variety), the entire plant being glabrous with a whitish bloom on all plant parts. There is little or no branching and full occupation of the land is dependent on density of planting. The leaves are pinnate, with several pairs of leaflets and a terminal-branched tendril. The flowers are large, butterfly-like, and may be white, pink or purple. The field pea seed is round and smooth; but the garden types are usually wrinkled, resulting from the presence of sugars as stored food (versus starch in round peas), which shrinks upon drying. Seed coat color of varieties range from green to yellow, to brown; while the cotyledons are either green or yellow. Split peas, from which the seed coat has been removed, are thus either yellow or green. Seed pods are inflated and contain 2 to 10 seeds, depending on the variety. Seed germination is hypogeal, i.e., the cotyledons remain in the soil, and only the sprout is pushed through covering soil.

Whole seed of some varieties, and occasionally in all varieties, may be resistant to water absorption on cooking; this is caused by hard seed coats, and is eliminated when processed as split peas for food.

Peas of the *P. sativum* type tend to branch very little, however, the crop roots fairly deeply on suitable soils. When thickly planted the roots fully occupy the soil profile but this occupation is not complete with thin stands of plants. This root system trait must be recognized in developing improved cultural practices.

Varieties

The flowers of peas are normally self-pollinated. When natural crossing is suspected, it is in conjunction with an infestation of thrips or other insects causing cross pollination. There are many regional types and strains of peas in collections made in the tropical and subtropical countries.

The Indian Agricultural Research Institute has several hundred of these. Most of the named varieties have been produced by plant breeders in Europe and North America. Some of these temperate zone varieties have been found useful in the tropics and subtropics, but this is fortuitous since evaluation and selection has been based on conditions pertaining to temperate regions. Diligent searches and collections of seed samples from all of the important pea-growing countries of the tropics and subtropics would doubtless lead to identification of types or selections with favorable adaptation to particular climatic and soil conditions, resistance to pests, high-yielding ability, and desirable plant and seed characteristics.

Local evaluation of available types and varieties should be undertaken, using the cultural practices designed to increase yields. Continuing evaluation of new collections should be made to find still better types, as well as hybridization of desirable parent stocks to produce new combinations.

Multiplication and distribution of pure seed of improved varieties should be simple, requiring only that off-types be rogued out of seed fields. Farmers may save their own seed without serious danger of losing hereditary traits. Confirmation of identity of a specific strain is needed to avoid adulteration by physical mixing of seed through careless handling.

Culture

Fertilization

Being a legume, peas do not respond to nitrogen fertilizers, where the roots are well-nodulated with nitrogen-fixing bacteria. However, peas have a high content of other mineral elements, and any soil deficiencies in these elements must be corrected by appropriate fertilization to produce high yields. The major mineral elements required are phosphorus, potassium, calcium, magnesium, and sulfur. When ordinary superphosphate is used as a source of phosphorus, the needed amounts of calcium, magnesium, and sulfur are supplied automatically in the superphosphate. But when concentrated superphosphate is used, sulfur is not provided, and must be supplied by other means.

Phosphate fertilizers must be properly positioned, just below the seed, to remain in available form for plant use.

Placing superphosphate in bands minimizes inactivation. A practical method of positioning superphosphate is to open a shallow furrow, spread the fertilizer, then cover with 5 to 8 cm of soil, place seed thereon, and cover seed with another 3 to 5 cm of soil.

Where field trials using proper placement of fertilizer have not been conducted to determine amounts needed, it is suggested that fertilizer initially be applied at a rate to deliver about 50 kg/ha of P_2O_5. In potash deficient soils to balance the phosphate, potash fertilizer may be used at the rate of 25 kg/ha of K_2O. Even larger amounts may be required on some soils.

There is a strong probability that many tropical and subtropical soils also are deficient in one or more of the "trace" elements that are needed in only small amounts. These are manganese, iron, copper, zinc, boron, and molybdenum. Until such time as specific deficiencies in trace elements are identified for specific kinds of soils, it may be useful to apply animal manures that usually contain small amounts of these elements. To conserve limited supplies of dung and obtain maximum results, it is suggested that the dung be added in the bottom of shallow furrows along with superphosphate. If this proves impractical, the dung may be placed in the bottom of a furrow during plowing, as nearly below the intended crop row as may be possible. Severe deficiencies of any trace element may prevent responses to superphosphate and potash that would otherwise greatly enhance yields.

Seed Bed Preparation

The seed bed should be free of growing weeds, all trash removed or plowed under, and large clods broken up. The field should have been handled to conserve rainfall by reducing runoff and storing moisture in the soil profile. If preparation precedes the occurrence of rains, the surface soil should be left rather rough to facilitate rapid penetration of rains when they occur, and retard runoff.

Planting

Since neither the tops nor the roots of peas are well-branched, full occupation of the land depends on sufficient density of seeding to fully utilize the soil and sunshine. Rows should be spaced as close as feasible for handling the crop, about 60 cm apart, and sufficient seed used to produce a plant every 5 cm in the row. Depending on seed size for the variety, such density of planting will require 80 to 100 kg/ha of seed for small seeded varieties, up to 140 or 160 kg/ha for larger seeded types.

Seed should be treated before planting if a good stand is to be achieved. Seed viability should be 80% or higher and planted no deeper than 5 cm to facilitate emergence of sprouts, particularly in soils that tend to crust under successive rains and drying periods.

Weed Control

The types of weeds that are troublesome in peas are similar cool-season annuals and some cool-season perennials. Weed competition may seriously reduce yields, although band placement of fertilizers and dung, and the withholding of all nitrogen fertilizers, avoids undue stimulation of weeds between rows of peas. Weeds should be killed while still young, before there is significant competition with peas for moisture and nutrients. If pulling or hoeing of weeds cannot be done at early growth stages, it may be necessary to use a selective herbicide that will kill the weed species present without injury to the peas. Since peas do not have robust root systems at best, any damage from pulling or hoeing weeds will reduce grain yields.

Disease Control

Numerous diseases caused by bacteria, fungi, viruses, and nematodes affect the leaves, stems, pods, seeds, and roots of peas grown in the tropics and subtropics, resulting in reduced yields and seed of an inferior quality. Pea pathogens are transmitted by various means, including wind, insects, drainage water, plant refuse, and seed.

Planting peas year after year on the same land that has a history of soil-borne diseases can lead to increased multiplication of some of these pathogens in the soil, and unless crop rotation is practiced, preferably in association with deep plowing of the crop refuse remaining on the soil surface, yields may be reduced with each successive pea crop until the cultivation of peas on this land will no longer be profitable. Control of some soil-borne pea diseases, such as Fusarium wilt and root rot, that survive for many years in the soil is only feasible by growing resistant pea varieties. Wherever peas are grown, it is a very important practice to plant seeds which are disease-free since some pea pathogens are carried on the seed.

Most research on control of pea diseases by plant resistance, chemicals, and cultural practices has been done in the temperate regions. Although some of these control measures can be used successfully in the tropics and subtropics, much of the research on control of pea diseases in these areas will have to be done locally.

No recommendations are made for treating the seed prior to planting since seed treatments must follow in-country regulations. Seed treatment is very important for the control of pathogens on the seed surface and in the soil. At times, the only way to insure a good stand of pea seedlings is to treat the seeds with some chemical. However, treated seed should never be used for human food or livestock.

Insect Pest Control

The grower may invoke two preventive measures against insect pests that are inexpensive, and one protective measure after infestations occur. The preventive measures are: (1) plant varieties that are resistant and (2) practice field sanitation. Until now little improvement work has been done in selecting varieties resistant to insect pests, although this means of control is very promising for the control of some pests. Timing may be more important than early treatment for the control of certain insects. The leaf weevil, for instance, if treated too early may require a second treatment. The same may be true of the pea weevil. Aphids must be treated early to prevent virus infections.

Field sanitation should also include avoidance of growing peas near crops and weeds that could supply insects or diseases to the pulse crops. In Iran, for example, pea leaf roll virus causes yield loss in pulse crops, particularly when crops are grown near an important reservoir host like alfalfa. This virus is carried from alfalfa to pulses by aphids.

When infestations of injurious insects develop, it may be necessary to move promptly to apply insecticides effective on the specific insect before damage is serious. Early treatment when control becomes necessary is highly essential. (see footnote)

Footnote: For further information on Crop Protection, see Chapter 4 in book on "Tropical Agriculture", by Wrigley, (Reference list following Chapter 40).

Harvest

In drier regions, peas may be left in the field to complete drying of the seed before harvest. Moisture content should fall to about 10% to permit safe storage without danger of molding. Harvest should be prompt after the grain is dry to prevent deterioration of peas intended for seed.

Threshing

Threshing may be done by hand flailing, or by traditional threshing machines adjusted to prevent splitting or cracking seed.

Protection Against Storage Insects

Insect damage to stored grain usually begins in the field, and may spread rapidly in storage. Such losses may be prevented. All storage structures and containers should be treated with malathion or other effective insecticides before being filled. However, poisonous insecticides must not be applied to the peas. Fumigation leaves no residual protection. Residual protection is possible with 1% malathion dust applied to stored seeds. Because of the low mammalian toxicity of malathion, its use for stored seed protection in developing nations is encouraged as there would be little chance of its harming humans or livestock.

The pea crop should be fumigated before going into storage, to kill weevils, maggots and other pests brought from the field. The stored crop should be inspected periodically, and fumigated again when new infestations are detected. For further details on fumigation, see the Chapter on Maize, section on control of storage insects.

CHAPTER 19

SECONDARY FOOD LEGUMES [1]

All the foodgrain legumes, in this chapter are edible, and constitute important crops in certain regions. In general, they are not as widely grown as the major foodgrain legumes discussed in previous chapters, but they have particular value in being rich in proteins and, thus, somewhere in the world, having important nutritional value as extenders of animal proteins (meats, milk, eggs, and fish) that are scarce and costly.

The crops in this chapter have been separated by Dr. K.O. Rachie [1] on the basis of their rainfall requirements. He cautions, however, that in making such fine distinction in requirements, considerable overlapping in regions is certain to occur. Much of the information given in the chapter is from Dr. Rachie.

In the pages that follow, the various crops will be discussed in this order:

Botanical Names	Common Names
Semiarid regions (less than 500-600 mm annual rainfall):	
Cyamopsis tetragonolobus (C. psoraliodes)	cluster bean, guar
Kerstingiella geocarpa	Kersting's groundnut
Phaseolus acutifolius var. latifolius	tepary bean
Vigna acontifolia (Phaseolus acontifolia)	moth bean or mat bean
Voandzeia subterranea	bambara groundnut or Madagascar nut
Lathyrus sativus	grass pea, vetchling, khessari, chickling vetch, sweet pea
Semiarid to subhumid regions (600-900 mm annual rainfall):	
Lablab niger (Dolichos lablab)	hyacinth bean, lablab, bonavist

[1] Edited by K.O. Rachie, Leader, Grain Legume Improvement Program, International Institute of Tropical Agriculture, Ibadan, Nigeria

Macrotyloma uniflorum (*Dolichos biflorus*)	horse gram
Parkia spp.	African locust bean

Subhumid regions (900-1200 mm annual rainfall):

Canavalia ensiformis	jack bean or horse bean
C. gladiata	sword bean
Vigna angularis	adzuki bean
Vigna umbellata (*V. calcaratus*, *Phaseolus calcaratus*)	rice bean

Humid and very humid regions (above 1200 mm annual rainfall):

Mucuna pruriens var. *utilis*	velvet bean
Mucuna sloanet	horse-eye bean
Pachyrrhizus erosus (*P. tuberosus*, *Dolichos bulbosis*)	Mexican yam bean, potato bean or manioc bean
Phaseolus lunatus	lima bean
Psophocarpus tetragonolobus	winged bean
Sphenostylis stenocarpa	African yam bean

Winter annuals or cool weather legumes:

Lathyrus sativus	grass pea, vetchling, khessari, or chickling vetch
Lupinus albus	white lupine, sweet lupine
Lupinus angustifolius	"sweet" strain of blue lupine
Lupinus lutens	"sweet" strain of yellow lupine
Vicia spp.	vetch (various kinds)

Plant disease susceptibility and losses from insects for many of these species are classified as being very low. In many cases, this could quickly change with an increase in or concentration of areas seeded to the crop. Average yields per hectare can be expected under normal growing conditions in areas where the crop is regularly grown. Averages will vary between and within countries and areas, and maximum yields may be exceeded, but they should not be used in estimating expected yields, especially in areas new to the crop.

Semiarid Regions with Less than 500 to 600 mm Annual Rainfall

Cyamopsis tetragonolobus, cluster bean, guar, is a bushy, robust herbaceous annual that grows in 90 to 120 days in the tropics and subtropics, especially India. It does well on alluvial/sandy soils and likes high temperatures. Yields of dry seed average 400 to 600 kg/ha and go as high as 1,600 kg. The green pods are used as a vegetable. The crop is also grown for green manure, as a fodder crop, and as an industrial crop for the mucilage extracted from the seed. Its susceptibility to pests and diseases has been low, especially in drier climates.

Kerstingiella geocarpa, Kersting's groundnut, is a small annual with underground fruiting that grows in Africa. It is similar to bambara groundnut in size, growth habit, duration of growth, soil and climate preferences/tolerances, and its low susceptibility to pests and diseases; but it is a much less important crop than bambara groundnut. It grows well on dry, poor, sandy soils and requires high temperature and sunshine. Dry seed yields average about 500 kg/ha. Both the unripe and mature seed are used as pluse.

Phaseolus acutifolius var. latifolius, tepary bean, is an annual originating in northwestern Mexico and southwestern U.S.A., it matures in 60 to 90 days and is also grown to a limited extent in India and Burma. It is suberect, herbaceous, bushy or recumbent, 25 cm high. It does well on dry soils and does not tolerate waterlogging. It has medium susceptibility to pests and diseases and produces a maximum 1,500 kg/ha of dry seed. Used for pulse, it averages 400 to 700 kg/ha. As a forage it produces 5 to 10 tons of dry hay.

Vigna acontifolia, moth bean or mat bean, is an annual that grows to maturity in 65 to 90 days in India and Burma. It is a slender, creeping, hairy, herbaceous plant 10-30 cm high. It is planted on light sandy soils near the end of the rainy season and grows mainly on stored moisture. It is also grown as a hot-season crop under irrigation, and is often planted in mixtures with sorghum, millet, lablab, and pigeon pea. It produces as much as 1,600 kg/ha of dry seed averaging 300 to 400 kg. These tiny seeds are very rich in protein and thus are an excellent supplement for diets composed largely of cereals. Also, the green pods are eaten as a vegetable and the crop is sometimes used for hay and green forage.

Voandzeia subterranea, bambara groundnut or Madagascar nut, is a small, bunchy, annual herb with erect long-stalked, trifoliate leaves. It matures in 90 to 150 days, forming its fruits underground. It is found widely in Africa, especially in the semiarid to subhumid southern fringes of the Sahara, in eastern Africa from Sudan to Rhodesia, and in the Malagasy Republic. It has a preference-tolerance for dry, poor soils and high temperatures, and has very low pest and disease susceptibility. Cultural requirements are quite similar to those for groundnuts, but it is much more drought tolerant . Maximum yields of dry seed are about 2,600 kg/ha and average about 750 kg. Unripe seeds are eaten fresh; ripe seeds are used as pulse. It is high in protein, but unlike ordinary groundnuts, contains very little oil. It is the most important pulse in Africa after cowpeas -- and ordinary groundnuts, an industrial crop.

Semiarid to Subhumid Regions (600-900 mm Annual Rainfall)

Lablab niger, hyacinth bean, lablab, bonavist, is a short-term perennial that is frequently grown as an annual in 75 to 300 days in South Asia, Latin America, and Africa. It has many forms and varieties -- some twining (climbing), some bush forms. It requires good drainage, but tolerates poor soils and low fertility. It is moderately resistant to pests and diseases. Average production of dry seed is 400 to 500 kg/ha with yields reported as high as 1,150 kg/ha. Young pods and green beans are used as vegetables and dry seeds, for pulse and feed for livestock. It is also used for forage and green manure.

Macrotyloma uniflorum, horse gram, is a low slender, semi-erect, herbaceous annual that matures in 120 to 180 days, reaching a height of 20 to 30 cm . It is grown extensively in southern India, but also in Malaysia, West Africa, and the West Indies. It tolerates very poor soil (but not alkaline soils) and has only moderate susceptibility to pests and diseases. Its average yield of dry seed is 200 to 300 kg/ha, but produces as much as 1200 kg/ha. Culture is similar to mungbeans. Dry seeds are used as pulse and animal feed. It is also grown for green manure and for fodder.

Parkia spp., African locust bean, is a perennial tree that grows 10-30 meters in height on a wide range of alluvial soils. It has had very little susceptibility to pests and diseases.

Dry seed production averages about 350-500 kg/ha. The dry seeds are fermented as flavoring. The fruit pulp is also cooked.

Subhumid Regions (900-1200 mm annual rainfall)

Canavalia ensiformis, jack bean or horse bean, is a bushy, erect perennial that grows to a height of 1 to 2 meters in 180 to 300 days. It has widespread distribution in lowland tropics around the world. It is deep-rooted, and drought resistant, but also tolerates shade and some waterlogging. Dry seed yields average 800 to 1,000 kg/ha with yields as high as 4,600 kg. Cultural practices are similar to those for cowpeas. Both the green pods and seeds as well as the ripe seeds (less frequently) are eaten; however, after severe temperature changes during the growing season, either the green beans or the ripe seeds are sometimes toxic. (Apparent toxin is HCN.) It is grown for forage and cover, and urease and lectin are extracted for medicinal purposes. C. gladiata, sword bean is a closely related species but it is a large climber. It occurs extensively in the humid tropics of Africa and Asia.

Vigna angularis, adzuki bean, is a bushy, erect annual of Chinese orgin used for food in Asia and in other subtropical regions. The plants are 30 to 75 cm tall, depending on variety. There are very many varieties, differing widely in plant size, seed color, and other characteristics. Is adaptation and culture are similar to those of the soybean, but unlike the soybean, it is low in oil content. It is useful as a protein supplement in diets.

Vigna umbellata, rice bean or red bean, is a short-term perennial that grows as an annual and matures in 60-90 days in Asia. Its type of growth ranges from erect to suberect to twining, with stems as much as 300 cm long, but usually reaching a height of only a third of a meter. It grows on light to heavy soils after or before rice. It is reputed to be susceptible to root knot nematodes which may account for its growth on soils periodically flooded for rice, thus controlling nematodes. Cultural practices are similar to mungbeans, with average yield of dry seed 200-300 kg/ha and attaining yields as high as 1,200. The dry seeds are rich in protein and are used as pulse; the green seeds and pods are eaten as a vegetable and the crop is also grown for green manure and for fodder.

Note: Phaseolus vulgaris, phaseolus beans, field beans (dry beans and stringbeans in the USA) and Glycine max, soybeans, are in this rainfall grouping.

Humid and Very Humid Regions (Above 1200 mm annual rainfall)

Mucuna pruriens var. utilis, velvet bean, is a perennial, herbaceous climber 3 to 8 meters in length that matures in 240 to 300 days in Africa. It requires high temperatures and a humid climate but will grow on poor, sandy loams. It has had very low susceptibility to pests and diseases. Dry seed yields average 700 to 1,000 kg/ha. The seeds are sometimes used as pulse, and the crop is also grown for green manure, cover, and forage.

Mucuna sloanet, horseye bean, is a perennial, herbaceous climber, 3 to 10 meters in length, that fruits in 240 to 360 days. It requires high temperatures and humidity and a well-drained soil. It has had very low susceptibility to pests and diseases. Ripe seeds are sometimes used as a pulse in thickening soups in eastern Nigeria.

Pachyrrhizus erosus, Mexican yam bean,potato bean or manioc bean, is a climber that grows to 2 to 5 meters in length and produces good-sized tubers in less than a year. It is a perennial through its tuber, but the stems and leaves are annuals. It is native to the American tropics, but is grown widely in tropical countries on all continents. The crop is usually propagated by pieces of mature tubers, but can be grown from seeds planted about 30 cm apart in rows spaced 90-100 cm. Vines should be supported on poles. It needs well-tilled, sandy loams and a humid climate. It has had very low susceptibility to pests and diseases and is one of the most vigorous growers and pod producers among the tropical legumes in high rainfall areas. Tubers are eaten raw or cooked, the green pods are sometimes eaten as a vegetable. The ripe seeds are reputed to be toxic to man and animals.

Phaseolus lunatus, lima bean, is a perennial twining climber, but there are also bush types. It requires 100 to 270 days to grow and is of major importance in the African lowland tropics as well as many other tropical areas where it needs a moist climate and well-drained, aerated soils. Its susceptibility to disease has been very low. Dry seed production averages 500 to 600 kg/ha with yields as high as 2,800 kg. It is eaten mainly as dry beans as pulse, but the green beans, young pods, and leaves are also eaten as a vegetable. Note: The dry seeds may be toxic (HCN).

Psophocarpus tetragonolobus,winged bean, is a twining, glabrous, herbaceous perennial plant that grows to fruiting in 180 to 270 days in tropical Asia, Papua, and New Guinea. It needs a humid climate and loamy soils. Its susceptibility to pests and diseases has been very low. Yields of dry seed average 400-500 kg/ha, but run as high as 2,500. Fresh green pods, leaves, and tubers are used as vegetables, the dry seeds as pulse. It is also grown for green manure and forage.

Sphenostylis stenocarpa, African yam bean, is a twining, climbing, or procumbent, herbaceous perennial of 3 to 6 meters that grows to seed production in 150 to 300 days, in lowland tropics of Africa where it is an important crop. It needs a humid climate and well-drained loam soils. Its susceptibility to pests and diseases has been low. Yields of dry seed averages 300 to 500 kg/ha and range up to 1,200 kg. Tubers are eaten fresh or cooked; dry seeds are eaten as pulse.

Winter, or Cool Weather Legumes Grown for Food

Lathyrus sativus, grass pea, vetchling, khessari or chickling vetch, requires a subtropical or temperate, not a tropical climate. It is grown at higher elevations during a cool season in India, the Near East, and North Africa. The plant grows erect or nearly so, about 75 cm tall although some forms are procumbent. The stems and leaves somewhat resemble field peas. It is grown primarily because of its ability to produce a modest crop despite limited rainfall during the growing period. Cultural practices resemble those for lentils and chickpeas. The seeds are rich in protein, but many varieties contain toxic alkaloids in the seed that cause dangerous systemic disorders in man. Its culture for food must be rigorously limited to nontoxic strains.

Lupinus albus, white lupine or sweet lupine, is an annual with stems 40 to 120 cm long (depending on variety) with 5 to 7 leaflets per leaf and white flowers and seeds. It is grown in cooler seasons (higher altitudes in the tropics) in much the same manner as field peas. The crop prefers soils of moderate fertility and is most productive when the "rainy" season is fairly cool.

L. augustifolius, "sweet" strain of blue lupin, and *L. luteus*, "sweet" strain of yellow lupine, are related species in which strains have been developed that are "sweet", i.e., they have relatively low toxic alkaloid content. A process for essentially eliminating the remaining alkaloid has been worked out in Chile. These species appear superior to *L. albus* on sandy, moderately acid soils of low fertility. They are small-seeded types.

The bitter lupines, with an alkaloid content of 0.35 to 3.0% have been consumed for centuries by the Indian population of the Andes in Colombia, Ecuador, Peru and Chile. Information available indicates that lupines are also consumed in Italy and

Iran.

The so called "sweet lupines" with an alkaloid content of only 0.001 to 0.02% are a new development and their seeds are now being extensively investigated as a raw material for high protein foods. Even with the alkaloid content low, it is considered by the Chileans that its complete removal is essential as it may be a potential health hazard. Sweet lupine seeds retain also a slight bitter taste.

Experiments have been conducted in Chile which have resulted in a processed product with much the same characteristics as was developed for the soybean by the University of Illinois. The grain is first adequately dried, then dehulled and leached with warm water for a certain period, at the pH which corresponds to the isolectric point of the protein. Subsequently it is shredded and dried; and, if necessary, finally ground in an Alpine mill.

Vicia spp., vetches of various kinds, although primarily a forage and cover crop, are grown for food in some areas. For example, Turkey produces vetch seed and exports some of it to Japan for use as a food legume.

CHAPTER 20

GROUNDNUTS [1/]
(*Arachis hypogaea*)

Other Common Names: peanuts, goober pea, pistache de terre, earthnuts

The groundnut is both a food grain legume and an oil seed crop. It is widely grown in the tropics and subtropics for direct use as food, for the oil, and for the high protein meal produced after oil extraction.

Geographical Distribution

Groundnuts are believed to have originated in the upper Plata basin in what is now eastern Bolivia and to have spread rapidly throughout the tropics and temperate zones following the colonization of the Americas. Groundnuts are grown widely as a crop of major importance in the following countries of the tropics and subtropics: in Asia - India, China, Burma, Indonesia, and Thailand; in Africa - Nigeria, Senegal, Sudan, Zaire, Niger, Uganda, Upper Volta, Cameroon, Malawi, Chad, and Mali; in South America - Brazil, Argentina, and Paraguay; in Central America and the Caribbean - Dominican Republic and Mexico; in North America - the United States. The yields per hectare may be used as an indicator of the degree to which improved technology is being applied. In contrast to the North American production under a relatively high level of technology that produces average yields of 2300 kg/ha, and top yields above 3000 kg/ha, Asiatic yields generally are less than 1000 kg/ha, African yields about 2/3 of Asiatic yields, and South American and Caribbean yields about equal to Asiatic yields. There appear to be substantial opportunities to make effective use of known technology in the tropics and subtropics; but there is doubtless much research that should be undertaken to adapt research results from other areas to the ecological conditions in each groundnut producing country.

Utilization

Groundnuts constitute a major crop for subsistence food; as a high-protein crop to balance diets high in cereals and starchy foods, supplementing animal proteins; as an oil

[1/] Edited by Ray O. Hammons, Research Geneticist and Technical Advisor (Peanut Breeding), Southern Region, Agricultural Research Service, U.S. Dept. of Agriculture, in cooperation with University of Georgia Coastal Plain Station, Tifton, Georgia 31794 and B.E. Caldwell, Staff Scientist (oil Seeds), National Program Staff, Agricultural Research Service, U.S. Dept. of Agriculture, Beltsville, Maryland 20705 crop for home use in cooking, lighting, and as a food constituent; and as a cash crop for domestic markets and foreign trade. The principal importing countries are most of Western Europe, Japan, Hong Kong, Singapore, Malaysia, Venezuela, and Algeria. The crop is marketed as unshelled nuts, oil, or meal.

The crop is usually grown in rotation with maize, sorghum, and millet, and as an interplanted crop in various row crops. The vine residues, after the pods are removed, are excellent protein feed for horses and for ruminant livestock. The crop may be grown with little or no mechanization, with partial mechanization, or as a completely mechanized crop. With moderate attention to control of spoilage damage, groundnuts store well; they may be processed for oil and meal, or roasted with primitive home facilities; or processed with advanced technology.

As an edible oil crop, groundnuts compete with sesame, sunflowers, and soybeans; but each has somewhat different ecological adaptations.

Groundnuts As A Foodstuff

Whole groundnuts, and groundnut meal produced by expressing the oil, are rich in protein, minerals and vitamins. The oil is a satisfactory cooking oil, useful also for home lighting, as a raw material for making margarine, and directly as an essential food. The whole groundnuts (without shells) average 26% protein, 43% oil, 24% carbohydrates, and 2.7% minerals. They are rich in calcium, phosphorus and iron. They constitute an excellent source of the vitamins thiamine, riboflavin, and niacin, but not of vitamin A or ascorbic acid. The meal is much richer than the whole groundnut in protein, minerals and vitamins.

The groundnut protein resembles most other plant proteins in being somewhat deficient in the two amino acids essential for human diets, namely, methionine and cystine, in comparison with animal proteins. However, groundnut protein serves as an excellent supplement to cereal grains and starchy crops that are low in lysine and tryptophan, in which groundnuts are rich. Cereals and starchy crops are comparatively high in methionine and cystine. Using animal protein as the standard complete protein for human diets, groundnuts serve as an "extender" of the scarce and expensive animal proteins.

Adaptation

Groundnuts do not tolerate low temperatures. They need a warm climate, with moderate rainfall or irrigation during the growing season, and prefer hot, dry weather during seed ripening. The crop is not adapted to regions of continuing heavy rainfall; since the difficulty of curing the crop without molding of the seeds is prohibitive in humid regions. The bambarra groundnut is grown in humid regions.

Early varieties will mature in 90 to 100 days, and other varieties require as much as 140 days. This comparatively short growing period may permit production of a second crop (following a cereal) on the land in the same year.

Soil type and condition is highly important for groundnut production. Savanna lands and similar ecological zones are preferred, but within such zones, well-drained, sandy loams are best. Since the ripe crop of pods is borne under the soil surface and must be dug out, a friable soil is highly advantageous. Also, such soils favor rapid maturation of the pods and minimize mold damage.

Groundnuts are reputed to grow well on soils low in fertility, but this is true only when they follow another crop that has been well fertilized (cotton, maize, sorghum, etc.). The groundnut apparently utilizes rather well the residual mineral fertilizers left from the preceding crops.

Description

The groundnut is a legume; it is not a nut in the technical sense, but is a type of pea. It is a warm season, annual, herbaceous plant, that produces a central upright stem with few to numerous branches that range in habit from nearly erect to prostrate. There are two main botanical types: (1) the Spanish-Valencia type in which the plant is generally erect, matures early, has pods clustered about the base of the plant and the seeds possess little fresh dormancy; and (2) the Virginia type in which plants are spreading (runner) to upright (bunch), in habit, mature later, have pods dispersed along the secondary and tertiary branches, and the seed possess appreciable fresh dormancy.

The plant has a well developed taproot with numerous lateral branches. The root system is well nodulated, and the plant is, therefore, not dependent on soil nitrogen nor on fertilizers to meet its high nitrogen requirements.

The plant has pinnately compound leaves with two pairs of leaflets. Flowers are borne in the leaf axils, above ground, singly or in clusters of about three. The flowers are self-pollinated. After pollination, the ovary stalk "peg" elongates rapidly and pushes the fertilized ovary into the soil, where it develops into a pod. The pods may have 1 to 3 (or more seeds) each, depending on variety and growing conditions. The pod develops only under the soil surface, and thus, it is quite important that the soil be sufficiently friable for the "pegs" to penetrate easily.

The seed is a straight embryo, with a thin papery seed coat, which assumes various colors at maturity (depending on the variety). The seed coat is not grown fast to the seed and is easily slipped off after roasting or cooking. Seed dormancy is characteristic of some varieties, this period extending for weeks or months when left in the soil; but the "rest" period is broken by exposure to temperatures above 37°C for a few weeks. Seed size varies with variety, from 2000 to 3000 seeds per kilo. Under proper storage conditions (low humidity, and seed well dried), the seed (in the pod) retains its viability for 3 or more years.

Varieties

There is a limited amount of cross-pollination of groundnuts under field conditions, and the progeny of these natural hybrids provide a rich source of variability for making selections. Another--and rarer--form of variant, the mutant, may also occur. Thus, there are a great many types and varieties found in all groundnut producing regions. After the initial few plant generations, the variants resulting from natural crossing generally breed true, so that the subsequent selections can be maintained without hereditary changes, provided that off-types are removed in all seed producing fields. The dominant varieties and types of any regions show a strong tendency toward adaptation to local climatic and soil conditions, which has made them more productive. There is a continuing opportunity to select strains that are capable of responding to improved cultural practices, that are more resistant to specific pests, and have preferred growth habits and seed characteristics.

Evaluation of varieties and strains introduced from other regions with similar climatic conditions is likely to provide rapid benefits, if field trials are conducted under cultural conditions favorable to high yields, with all strains given equal treatment. In addition to total yields, and growth characteristics that favor ease of production and harvest, selection should emphasize market acceptability. Since the strains or selections generally breed true, there is no difficulty in maintaining the identity and genetic purity of superior selections. Growers may save their own seed without loss of hereditary traits, with limited guidance on removal of off-types, and with precautions against physical mixing of different strains.

Culture

Rotations

Groundnuts should be grown in rotations with other crops, such as maize, millet, sorghum, and cotton; and there is some evidence that periodic growth of a forage grass or legume for livestock feed, enhances subsequent yields of groundnuts in tropical and subtropical regions.

Fertilizers

Groundnuts do not respond to nitrogen fertilizers when the crop is grown on land naturally inoculated with root-nodule bacteria, or when seed has been inoculated before planting on new lands. The crop is believed to be capable of growing on soils of low fertility, but this is true to only a limited extent, when groundnuts follow other crops in the rotation that have been fertilized with mineral fertilizers. Groundnuts appear to be capable of using residual fertilizers in the soil. Since the plants and seed of groundnuts are quite high in mineral elements, the supply of these in the soil must be high to support high yields. The major elements required are phosphate, potash, calcium, magnesium, and sulfur. For all of these, it is essential that they be available for ready absorption by the root system. However, there is an additional requirement for calcium; this element must be present in the surface soil into which the pegs are inserted, to foster development of seeds. For the bunch-types of plants, additions of calcium may be made on 15 cm strips on both sides of the plant row. For runner-type plants, the entire surface soil should be treated. Finely ground limestone or gypsum (calcium sulfate) at rates to supply the equivalent of 100 kg/ha of CaO will usually suffice, although field trials should be made for more precise measures of the amounts required to maximize yields.

Positioning of mineral fertilizers in the soil is recommended, since many tropical and subtropical soils react promptly with phosphate fertilizers to render them unavailable to plants. Placing the fertilizer in bands, under the planted seed, greatly reduces the undesirable inactivation that would occur if the fertilizer were broadcast or mixed with the soil mass. A practical method is to open a shallow furrow, place the phosphate (and potash if needed) in a band in the bottom, cover with 5 to 8 cm of soil, place the seed thereon, and cover the seed with about 5 cm of soil. Field trials should determine the amount of fertilizer needed; but, if these have not been made, it is suggested that superphosphate be spread to provide 50 kg/ha of P_2O_5. Potash may be added at a rate to supply 25 kg/ha of K_2O along with the superphosphate.

It should be noted that ordinary superphosphate contains calcium, magnesium, and sulfur, sufficient to meet plant needs when this fertilizer is used. However, concentrated superphosphate does not contain sulfur; this must be provided from other sources.

On many strongly weathered soils of the tropics and subtropics, evidence is being found of serious deficiencies in "trace" elements needed in small amounts; and correction of these deficiencies is required to permit responses to the traditional mineral fertilizers. One or more of the following elements may be deficient; manganese, iron, copper, zinc, boron, and molybdenum. Until the necessary research has been done on major soil groups to determine specific deficiencies in trace elements, it may be practical to make applications of animal manures which usually contain small amounts of trace elements in a readily available form. It is suggested that dung be spread with superphosphate, in furrows, as described above. If this is not practical, the dung may be placed in the bottom of furrows during plowing, under the proposed location of the row.

Seed Bed Preparation

The seed bed should be mellow and friable, all living weeds killed, and trash removed. Fields should be managed to conserve rainfall by reducing runoff and storing rain in the soil profile.

Planting

Row planting is highly recommended; it is necessary for proper placement of fertilizer, for weed control, and efficient harvest. Planting should be done as soon as rains begin, to foster rapid germination of seed. Either shelled or unshelled seed may be used, but if unshelled seed is planted, the pods must be broken into two or more pieces to give prompt germination. Spacing of rows and distance between plants in that row must be adjusted to variety and probable rainfall. Smaller varieties may be planted in rows 60 to 70 cm apart, and larger varieties in 90 to 100 cm rows. Spacing of plants may range from 10 to 20 cm in the row. From 20 to 40 kg/ha of shelled seed (or double these amounts of unshelled seed) will suffice to plant one hectare. (NOTE: No recommendations are made on treating seed before planting, since such treatments are poisonous to man if surplus seed is eaten; and must follow in-country regulations.)

Weed Control

Groundnuts are not strongly competitive with weeds, and infestations seriously reduce yields, particularly in drier regions. Weeds not only exhaust soil moisture but also deplete nutrient supplies. Early removal of weeds reduces competition with developing groundnuts, and minimizes physical damage to the root systems of groundnuts. Pulling, hoeing, or tillage after blooming of groundnuts begins, interferes with "pegging" of the plant, and pod formation. If weeds are still present at blooming or later, it may be advisable to use a selective herbicide that will not injure the groundnuts, to avoid serious loss in yields. Groundnuts are reputed to be resistant to witchweed that attacks cereal grains.

Disease Control

Principal reliance should be placed on two preventive measures for control of plant diseases: (1) plant those varieties or strains that exhibit greater tolerance or resistance to locally prevalent diseases, and (2) practice field sanitation. Such sanitation includes use of crop rotation so that groundnuts are not grown on the same land in successive years, and removal of all plant refuse promptly after harvest. These practices greatly reduce the amount of inoculum that might infect new plantings.

The occurrence and spread of diseases is directly related to rains and air humidity. Regions and seasons with frequent rains and high air humidity are not favorable for groundnut production.

Qualitative genetic resistance to most of the diseases known to attack the groundnut is in its infancy compared to the advances made with the cereals for example. However, progress is being made. Genetic resistance to rosette is known and has been incorporated into commercial varieties. Resistance to rust is known and the genetic mechanism is under study. Genetic resistance to the most important disease, leafspot, is yet to be conclusively demonstrated in *Arachis hypogeae*, but occurs in certain wild *Arachis* species.

Insect Control

Preventive measures are important for protection against insects. Insecticides are not recommended since they may leave toxic residues in the seed, and the vines from treated plants are unsafe for feeding livestock. The preventive measures include: (1) planting varieties that are relatively resistant or tolerant to locally damaging insects, and (2) field sanitation. Rotation of crops so that groundnuts are not grown on the same land in successive years, and prompt removal of vines and trash after harvest, will greatly reduce abundance of harmful insects. Quantitative genetic resistance to certain insects (e.g. Diabrotica undecimpunctata howardi, the Southern Corn Rootworm) has been reported in one U.S. genotype. (see footnote on Crop Protection)

Harvest

Harvesting is a crucial aspect of groundnut production. The crop is ripe when the seeds are full grown with seed coat (skins) showing natural color of the variety, and the inside of the shell has begun to color. Groundnuts shrink badly when harvested too early. Since the crop of pods is below ground level, they must be lifted out without removing the pods from the vine. This is more easily done on sandy loams in friable condition. The main root must be broken, and the entire vine with attached pods lifted, either by hand tools or machines. The lifted plants may be cured in a windrow, with pods not exposed directly to the sun; except in more humid regions or seasons, they may be shocks or small stacks around poles to minimize contact with the soil. Curing continues until moisture content of the seeds falls to 10% or less.

Groundnut curing is particularly important, since it has been found that rapid curing is very essential to minimize the hazard of molding, that produces a toxin (aflatoxin) that makes the crop unsafe for use as food for man, or feed for livestock. The crop rarely suffers any significant molding until lifted out of the ground on well drained soils. Prompt and thorough drying of lifted plants prevents molding of the seeds. The presence of molding makes the crop unmarketable, and unsafe for home consumption as food. Windrows or small piles of the vines and pods must be turned over promptly, if rains occur during the curing stage.

Footnote: For further information on Crop Protection, see Chapter 4 in book on "Tropical Agriculture" by Wrigley (Reference list following Chapter 40).

Pods are removed easily from the vines when dried to the stage that the slender attachments are brittle. This may be done by hand or by machines. If there is any doubt that the seeds are sufficiently dry for safe storage, they should be placed in shallow layers on drying floors, and turned frequently, until thoroughly cured. Molding at this stage is just as serious as molding during the field curing.

Storage and Processing

Groundnuts store safely when moisture content of the nuts is brought down to about 10%, and the relative humidity of the storage room is about 60%. If there is evidence of any storage insect infestations, the crop should be fumigated promptly (See Chapter on Maize, section on storage insect control, for further details). Do not treat with poisonous insecticides.

The most common method of preparing groundnuts for human consumption is dry roasting until the nuts develop a light brown color. For oil extraction, the nuts are shelled, cleaned, and crushed into a pulp to open the oil cells as much as possible. For commercial oil extraction, the pulp goes to a cooker where the material is heated to about 110°C (235°F) in a humid atmosphere for 90 minutes. The oil is most commonly extracted by the hydraulic press plate method under a pressure of about 1900 kilos (4000 lbs). A less sophisticated home-processing method is cold pressing of the roasted peanuts, but the oil yield is necessarily much lower. In commercial extraction, a metric ton of unshelled (roasted) nuts may produce 265 kg of oil, 410 kg of meal, and 325 kg of shells.

CHAPTER 21

SOYBEANS 1/

(*Glycine max*), (formerly *Soja max*)

Other Common Names: soya, soja

The soybean is an ancient crop in the Orient, where it has long been used directly for food as a green vegetable, in a wide variety of fermented food products made from mature beans, and as the edible sprouts of germinating beans. In addition, oil is pressed out of the mature beans for foods and cooking, and the resulting meal is used as a food. These uses appear to have originated in China and subsequently spread to neighboring countries. The soybean did not receive much attention outside of China and the Far East until recent time and is still a minor crop in most of Latin America (except for Brazil), in Africa, and the Middle East.

In the United States, soybean grain did not begin to achieve major importance until the 1940's, when average acre yields of soybeans following heavily fertilized maize in the rotation began to climb from previous levels of 15 to 20 bushels per acre to the present average of about 35 bushels per acre (2100 kg/ha). The soybean was first grown as an industrial crop for extraction of oil (a high value product). The residual meal from modern oil extraction processes proved to be nutritious, high-protein feed for all classes of livestock. With some further refinement, soybean meal also began to enter human foodstuffs in the mid 1960's, and has increased in importance as a supplementary protein food. The meal is presently considered even more valuable than the oil, as a total product. Improved varieties and better cultural practices accompanied the growing of the soybean on soils of high fertility. Soybeans began to be exported from the U.S. extensively during the 1960's, reaching more than 14 million tons in 1973. The estimated exportation figure for 1974 is expected to be somewhat less than 1973.

This phenomenal growth of soybeans in the United States, has attracted interest in other parts of the world where environmental conditions are similar, especially in southern Brazil and similar zones with responsive soils. The crop is originally adapted to temperate zones, being considerably influenced by length of day (hours of sunlight). The shift

1/ Edited by Earl R. Leng, Professor Plant Breeding and Genetics, T. Hymowitz Assoc. Prof. Plant Genetics and D.K. Whigham, Asst. Prof. Agronomy, Dept. of Agronomy, University of Illinois, Champaign, Illinois 61801 from long days to shorter days stimulates the onset of blooming and seed set. However, in many strains the vegetative and reproductive phases proceed essentially normally under tropical daylengths.

The general use of soybeans as food in China and the Far East, has led to efforts to use soybeans outside of those regions as a home cooked food in the same manner as peas, beans and other pulses (Chapters 11-19). The direct use of soybeans, as food (without fermenting, sprouting, or extracting oil) has involved certain problems. There are some factors in raw whole soybeans that inhibit or retard protein digestion. Other components cause flatulence when consumed by man, although not as much as the usual dry beans. The practice often used to prepare kidney beans, by soaking several hours in mildly alkaline water (5 gm of baking soda per liter of water), discarding the soak water, and then boiling for 30 minutes in fresh alkaline water as before to convert whole soybeans into an acceptable foodstuff. There is no barrier to full digestibility of soybean meal produced by toasting following the extraction of oil, or to that of boiled whole soybeans. The high temperature denatures the inhibitors of digestion and also reduces the tendency to produce flatulence.

As an industrial crop, the soybean competes with other oil seed crops (groundnuts, sesame, sunflower, etc.) in yields and in crop value per hectare. As a protein food, the soybean also competes favorably with other food grain legumes and groundnuts. In the United States, soybeans and groundnuts each are capable of producing up to 3,000 kg/hectare under appropriate cultural practices. The choice of one of these in the U.S. depends on soil type, actual comparative yields, etc. Groundnuts do much better on sandy soils than on heavy soils. The reverse is true of soybeans. Yield trials of well adapted varieties of soybeans in direct comparison with other food grain legumes or oil seed crops should determine the profitability of growing soybeans in specific locations of the tropics.

Utilization

Soybeans grown as a green vegetable make an excellent foodstuff in immature stages of development, in the same manner as shelled green beans, peas, cowpeas, broadbeans, etc. The potential inhibitors to digestion are no problem at immature stages of soybean development.

The oil has many food uses, and also is a versatile oil with numerous uses in industry. These include the making of glycerine, insecticides, ink, rubber substitutes, paints and soap.

Soybeans as a foodstuff

The average compositions of whole soybeans and of the meal that is residual from oil extraction, are as follows:

	Protein	Oil	Carbohydrate	Ash
Whole soybeans	39%	18%	25%	4.8%
Soybean meal*	44%	0.5%	33%	6.0%

(*produced by the solvent extraction process)

Soybean meal is an excellent high-protein food. As a protein food, it is much higher than the grain legumes, 44% versus 20 to 25%, so that it serves as a useful supplement to the protein-poor cereal grains. The meal is rich in minerals, particularly calcium, phosphorus and iron, and also has good to excellent content of the vitamins thiamin, riboflavin, and niacin. In common with other leguminous crops, the protein is somewhat deficient in 2 of the essential amino acids -- methionine and cystine; these are usually sufficient, however, in cereal grains. It may be also used as an "extender" of the well-balanced animal proteins (meat, milk, eggs, fish).

Soybean oil is used for cooking, for making margarine, salad oil, and in baked goods. Soybean flour (made from the meal) may be mixed with wheat flour (up to 20%) to produce a wide variety of baked goods, candies, ice cream, and pastries, that are much higher in protein than products made with cereal flours alone.

Adaptation

The climate requirements for soybeans are about the same as those for maize. There is need for moderate moisture supplies to facilitate germination and early plant development, but the crop will withstand short periods of drought after the plants are well established. In general, combinations of high temperatures and low rainfall are unfavorable, in terms of grain, and oil yields and oil quality. A wet season is not unfavorable, provided the soil does not become water-logged. The period of germination may be critical; soil temperatures should be above 15°C, and soil should be moist at planting time. Growing temperatures between 20 and 25°C appear to be optimum.

Soybeans grow on nearly all well drained soils, but are especially productive on fertile loams. They are not as sensitive to acid soils as many other legumes. They have one highly essential requirement -- the seed must be inoculated with fresh (viable) soybean nodule bacteria to meet the high nitrogen requirements of the plant. No other strain of nodule bacteria will inoculate soybean plants; and fresh inoculation at planting time is a prime requirement, unless the field has recently produced a successful soybean crop -- in which case the soil is naturally inoculated.

Description

The soybean is an annual summer legume, is usually erect, bushy and rather leafy. Varieties range in height from 45 to 120 cm, with growth periods of 75 to 150 days. Most varieties have a well defined main stem that branches from the lower nodes when the plants have sufficient space. Many varieties of soybeans have a determinate growth habit -- that is, the plants reach a definite size, produce flowers and seed, and die. The first two leaves are unifoliate and the later leaves are trifoliate with a variety of leaflet shapes and sizes. As maturity approaches, the leaflets begin to turn yellow; they usually drop off before the pods mature. The entire plant is covered with fine tawny or gray colored pubescence.

Small purple or white flowers are borne on short stalks arising at nodes of the stems. The pods are small, straight or slightly curved, and range in color from light straw through shades of gray and brown to nearly black. Pods contain 1 to 4 seeds, that are round to elliptical in shape. The most popular commercial varieties have straw yellow seeds, but seeds of varieties may be greenish-yellow, green, brown, or black. The seed coats of light colored varieties may be mottled with brown or black, and this mottling is both hereditary and the result of environment, but does not normally affect grain quality.

Soybeans are normally self-pollinated, because pollination occurs before the flower opens. A small amount of cross-pollination rarely occurs, producing off types in the succeeding crop.

Varieties

There are at least 100 established varieties of soybeans grown in commercial fields in temperate zone countries. These range in growth period from 75 to 150 days, and have mostly been chosen for their adaptation to the sequence of long days for vegetative growth, and shorter days for blooming and seed production. There are types suitable for growing in the tropics or subtropics, but breeding programs doubtless will be needed to develop better adaptation in these. In particular, some of the varieties adapted to the Corn Belt and southern states of the U.S.A. are also suited to the subtropics and tropics.

Varieties differ widely in all plant and seed characters. The most important traits sought are high yield potential, resistance to locally prevalent diseases and insect pests, and the nonshattering of ripe pods. Collections of soybean varieties are maintained by the U.S. Department of Agriculture, and these may be supplemented by varieties from other regions, for field evaluation in the region where the crop is desired. Such field evaluation should be made using the cultural practices favoring high yields of soybeans, and giving all strains equal opportunity. This procedure should identify strains that will be useful in their present form, and also should indicate which strains could be used as parents for a full fledged breeding program.

Culture

Fertilization

Soybeans do not usually need supplemental nitrogen fertilizer, since the crop is a legume and meets its requirements for nitrogen through root nodules. However, the crop is unique in that only the soybean strain of nodule bacteria will produce nodules, whereas many other legumes are not specific as to strains of bacteria.

Soybeans have rather high requirements for mineral nutrients, especially phosphorus, calcium, magnesium, and sulfur. If ordinary superphosphate is used as fertilizer, it will supply all of these. However, if concentrated superphosphate is used, it contains little or no sulfur, which must be supplied by other means to meet deficiencies in the soil. Soybeans yield well on soils of high fertility, particularly when following heavily fertilized maize or sorghum.

The best indices of fertilizer needs are actual field trials on specific soils. Since the majority of tropical and subtropical soils are deficient in minerals for the soybean crop, it is suggested that ordinary superphosphate be applied at rates to deliver 100 kg/ha of P_2O_5. A critical point in applying these minerals is proper placement so they will not interact with the soil to become inert, and so they will be promptly available to the root system of the young plants.

These objectives can be achieved by placing the fertilizer in bands below the seed. A practical method is to open a shallow furrow, spread the fertilizer, cover with 5-8 cm of soil, drop the seed thereon, and cover with 3-5 cm of soil. Such placement may also be made by machines that spread fertilizer and also drop seed, for large scale commercial plantings. Machine planting is no more effective than hand planting done properly.

There is considerable evidence that crop yields, particularly of legume crops, suffer from deficiencies of "trace" elements when grown on tropical and subtropical soils. Those elements are manganese, iron, copper, zinc, boron, and molybdenum, and a deficiency in one or more of these may prevent any response to fertilizers. Until necessary research has been done to identify the deficient elements for each soil group, it is suggested that field trials be made on the value of animal manure added to the mineral fertilizers. Dung usually contains small amounts of the trace elements in available forms. The dung may be spread in furrow bottoms along with phosphate; or it may be placed in the bottom of a plow furrow, approximately beneath the intended plant row. Furrow placement conserves the supply of dung that is usually in short supply.

Seed Bed Preparation

The seed bed should be prepared as for maize. All living weeds should be killed, trash removed or plowed under, and larger clods broken up. Soybeans should be planted in mellow, moist soil to foster rapid germination. Soil crusting, resulting from heavy showers followed by rapid drying in sun, may impede plant emergence and produce thin and irregular stands. When planted in warm moist soil, germination occurs in 3 days, before crusts are likely to harden.

Planting

Soybeans may be grown in closely spaced rows without cultivation or in rows spaced to permit cultivation. Row planting is preferred where weeds constitute a problem. From 60 to 70 kilos of seed will plant 1 hectare when rows are spaced 60 to 90 cm apart. Seed should be planted rather shallow, 3-5 cm deep, in moist soil. The goal is to have plants spaced about 5 cm apart in the rows.

They may be grown in rotation with cereal grains, wherever witchweed (*Striga* spp.) is a serious pest, since this parasite does not attack soybeans (or other legumes); the abundance of witchweed is greatly reduced in the following crop. The soybean is a warm season annual, and there are shorter or longer growing season varieties that may be used to adjust to the "rainy season" between dry periods of the tropics, or to the warm season in the subtropics. (NOTE: No recommendations are made on treating seed before planting, since chemical treatments are poisonous to man if surplus seed is eaten, and must follow the in-country regulations.)

Weed Control

Soybeans do not compete strongly with weeds in early growth stages, and weeds should be removed before they stunt the soybean plants. Early weed removal, before the root systems become competitive, is essential. Pulling or hoeing, or cultivation should be done early while weeds are small and easily killed.

If weed removal becomes impractical because of the damage that would be done to the soybean root systems, it may be desirable to use a selective herbicide that kills the weeds without injuring the soybeans. The herbicide chosen should be one that is effective on the weed species in the field.

Disease Control

There are two preventive measures that are effective for disease control on soybeans: (1) plant a variety or strain that is resistant to the prevalent diseases, and (2) practice field sanitation. Field sanitation consists of measures that reduce the amount of disease inoculum that will be present when the crop begins to grow. It includes crop rotation, so that soybeans will not be grown on the same field in successive seasons, and prompt removal or plowing under of all crop residues after the soybeans are harvested. In general, it has not been found necessary to apply fungicides to the growing crop to control diseases.

Insect Pest Control

As with disease control, there are two effective preventive measures: (1) plant varieties or strains resistant to prevalent insect pests, and (2) remove all crop residues promptly after harvest. The residues may be fed to livestock or plowed under. These practices decimate the insect pest population, and reduce the number available to attack the new crop. It is possible that insect pests may become serious in spite of preventive measures. In such cases, the application of an insecticide should be made as soon as serious damage seems likely; early treatment is more effective than delayed treatment. The insecticide chosen should be one that is toxic to the specific insect pest. (see footnote on Crop Protection)

Harvest

Soybeans should be allowed to stand in the field until the seed is dried down to 10% moisture or lower. Drying proceeds rapidly in sunny weather after leaves have fallen. Such field drying requires that the variety being grown be a nonshattering type. The crop may be harvested by hand or by machine.

Threshing may be done by hand flailing, or by a threshing machine adjusted so that the seed is not cracked or split. If the grain is not completely dry when threshed, it should be spread in thin layers on a drying floor, and turned periodically until completely dried so that molding will not occur in storage.

Storage

Insects cause little or no trouble if moisture is low enough for satisfactory storage and storage facilities are weather tight. Soybeans need to be sufficiently dry (10% or lower) when placed in storage and maintained that way in order to retain viability from one growing season to the next.

Footnote: For further information on Crop Protection, see Chapter 4 in book on "Tropical Agriculture" by Wrigley, (Reference list following Chapter 40).

CHAPTER 22

SESAME [1/]
(*Sesamum indicum*)

Other Common Names: sim-sim, bene, benne, sesamo, ajonjoli

Geographic Distribution

Sesame is a very ancient food crop, grown largely in tropical and subtropical regions. It may be grown and harvested successfully without any mechanization; it has a wide variety of uses; and there are well-developed domestic and international markets for the seed. The major producers (in addition to China) are India, Burma, Pakistan, Turkey, and Thailand in Asia; Egypt, Ethiopia, Sudan, and Uganda in Africa; Venezuela, Colombia, Mexico, and Nicaragua in the Americas. The highest average yields reported for tropical countries are 1180 kg/ha for Egypt (under irrigation), 950 kg/ha for Saudi Arabia (irrigated), 830 kg/ha for Mexico, and 690 kg/ha for Colombia. These yields fall short of 2000 kg/ha reported for field production in the southern states of USA (grown with natural rainfall), indicating great potential from the application of modern technology to the culture of the crop. The development of non-shattering seed types, now under way, will doubtless increase the popularity of the crop, and stimulate much new research on improved varieties and cultural practices.

Utilization

Sesame seed is a major import throughout the world. It moves in substantial quantity to nearly all European countries. In Asia, the major importing countries are China, Japan, Hong Kong, Israel, Malaysia, Saudi Arabia, and Taiwan. In Africa, U.A.R. (Egypt) is a major importer. Unlike other oil seed crops, virtually all of the sesame crop is marketed as seed; there are no statistics on sesame oil or cake in foreign trade.

Sesame as a Food

The whole seed of sesame is used for food, after removal of the thin coat (hull) by abrasion; and the seed meal (after oil extraction) is a high protein food. The average composition of the whole seed and of the meal after oil extraction

[1/] Edited by D.M. Yermanos, Professor Agronomy, Dept. of Plant Sciences, College of Biological and Agricultural Sciences University of California, Riverside, California 92502 is as follows:

Sesame (%)	Protein (%)	Oil (%)	Carbohydrate (%)	Mineral matter (%)
Whole Seed	22	43	11	3
Meal	43	9	23	4

The protein of sesame differs from that of all food grain legumes and oilseeds (including groundnuts and soybeans) in that it is well supplied with the essential amino-acids -- methionine and cystine, but is deficient in lysine. Sesame protein can supplement food grain legumes in human diets; and it serves as an "extender" of the well-balanced but scarce animal proteins (meat, milk, eggs, fish). Sesame is an important food supplement for diets that are high in cereals, bananas, and other starchy foods.

Sesame is a major oil seed crop for the tropics and subtropics. The oil is used extensively for cooking, for direct use as a food in dressings of various sorts, and for lighting. It can be used for the production of margarine.

Sesame meal, produced by oil extraction of dehulled seed, is a very rich source of protein. Both the entire seed and the meal are high in calcium, phosphorus and iron. Both seed and meal are well supplied with the vitamins thiamin, riboflavin, and niacin.

Sesame cake, produced by extraction of oil without removal of the seed coat, is an excellent high-protein feed for poultry, swine, and ruminants.

Adaptation

Sesame is grown as a summer crop in subtropical regions, and in any season with adequate rainfall in the tropics. It thrives in warm weather, and tolerates considerable dry weather after the plants are well established. It is adapted to regions of moderate to abundant rainfall, but not to regions of heavy rainfall (rain forest conditions). Savannah zones are best suited for sesame, with production adjusted to the seasons when rainfall is adequate for crop growth.

Sesame is adapted to a wide range of soils, but prefers fertile, loamy soils. The crop will grow in regions of limited rainfall, on deep soils that store rainfall within the soil profile. The crop responds to complete fertilizers, since the seed has a high content of the elements supplied by fertilizers.

Sesame is accomodated in farming systems in various ways. There are short season and longer season varieties that permit use as a major crop, or as a secondary crop to supplement a major crop. It is labor-intensive in growing the crop, but harvest is very easy (except for precautions to avoid losing seed by shattering), and processing for home use is simple. Sesame seed and its products have wide acceptance in tropical countries.

Description

Sesame is an annual, erect herbaceous plant; varieties range from 40 to 200 cm in height. The stems are square-sided, longitudinally furrowed, and densely hairy. The leaves are borne on short stalks (petioles), and vary in shape from lanceolate to ovate-oblong, 3 to 17 cm long, and 1 to 6 cm wide. The flowers (3 cm long) are borne in axils of leaves, singly or in two's or three's. The flower shape is bell-like, with ruffled edges of the corolla; the color is pink or whitish, with purple or yellow blotches. The seed pod (capsule) is 2- or 4-celled, borne erect, oblong in shape, about 1 cm in diameter and 2 to 2.5 cm long. During the flowering period, the lower buds on the stem blossom first, and blooming proceeds upward to the top of the plant over a period of several days. The ripe pods dehisce by splitting at the tip; and all of the ripe seed may be easily shaken out by merely inverting the plant stalk. This pod characteristic makes hand-harvesting necessary to avoid seed losses, and has prevented mechanized seed production. The development of non-shattering types that are mechanically threshed will greatly increase the versatility of this oil crop.

The seeds of different varieties are creamy white, dark-red, brown, or nearly black. The light colored seeds are preferred in world trade. The seed coat is relatively thin, and easily removed by abrasion for direct use of the whole seed as a food, and for extraction of oil and production of meal as a high-protein food supplement.

Varieties

There are a great many varieties, types, and mixed lots of sesame seed available from the countries where the crop is important. The USA has made a limited collection of improved varieties, and of new types, particularly the non-shattering types, that should be useful in any country's search for more productive strains of sesame. Venezuela has maintained a breeding program for sesame, for some years.

Collections from India and from the Far East would doubtless contain other types worthy of field evaluation.

Since sesame is self-pollinated, any selections tend to "breed true", so that seed increase and distribution should be easily handled. Natural hybrids produced occasionally by cross-pollination by insects do occur, and the progeny of such hybrids shows considerable variability for several plant generations before selections then breed-true. These hybrids should be removed from seed fields, to maintain genetic purity of the variety being increased. However, these natural hybrids as well as hybrids intentionally produced by cross breeding may be useful in developing new varieties of sesame.

Field evaluation of types and varieties and of unselected mixed lots to determine their yielding ability, seed and plant characteristics, and resistance to diseases and insects should be carried out. In these yield tests, appropriate cultural practices should be followed to make possible a thorough evaluation of the full productivity potential of the crop. There is little merit in testing at inadequate levels of cultural management.

Varieties should be chosen that may be planted and grown during the season when rainfall will produce a satisfactory crop. Adaptation to the rainfall pattern, and probable supplies of water stored in the soil profile, are essential to success with sesame.

Cultural Practices

Fertilizers

Since sesame is not a legume, its fertilization differs sharply from that suited to legumes (food grain legumes, groundnuts and soybeans). Nitrogen fertilizers are highly important as a means of supplementing native soil fertility to meet the crop's requirement for higher yields. The optimum amount of nitrogen fertilizer should be determined by field trials. For the initial trials, it is suggested that the equivalent of 50 kg/ha of N be supplied. It may be broadcast before or immediately after planting, to be carried into the soil with subsequent rainfall.

The problem with mineral fertilizers is somewhat more complex, since these fertilizers should be placed in bands below the rows, to minimize interaction with the soil that would make the phosphates inert. Tropical and subtropical soils very often have great "fixing" power for phosphates, so that broadcasting or mixing such fertilizer through the soil mass produces scant plant benefits. A practical method for achieving effective fertilizer placement is to open a shallow furrow, spread phosphate (and potash) fertilizer in the furrow bottom, cover with 5 to 8 cm of soil, plant the seed thereon, and cover seed with about 2 cm of soil. Initial tests to measure a response to mineral fertilizers may well provide 50 kg/ha of P_2O_5, and 25 kg/ha of K_2O. The optimum amounts may be determined by using larger increments, until crop response ceases to increase.

In supplying phosphate, it should be noted that ordinary superphosphate contains the essential elements - calcium, magnesium, and sulfur. However, if concentrated superphosphate or ammonium phosphate is used, sulfur is not present and must be supplied by other means.

An additional soil fertility factor to be considered in the tropics and subtropics is the supply of "trace" elements that must be met to permit normal responses to fertilizers. These trace elements are manganese, iron, copper, zinc, boron, and molybdenum. Until such time as field tests have identified the deficient elements in particular soil groups, it may be useful to make applications of animal manures, that usually carry small amounts of these elements in available form. Animal dung may be spread with the phosphate in a planting furrow, or it may be spread separately in a plowed furrow approximately under the intended crop row. This method of using dung conserves supplies that are usually limited.

Seed Bed Preparation

Since sesame seed is small, it should be planted rather shallowly on a firm but mellow seed bed. All living weeds should be killed, and trash removed or plowed under. Since the crop is usually grown in regions of limited rainfall, land preparation should run across the slopes to aid in retention of rainfall, and to minimize runoff.

Planting

Planting of sesame should be made in moist soil, about 2 cm deep, to foster rapid germination. This is particularly important on soils that are likely to become crusted as a result of heavy showers followed by sun drying. Rows should be spaced about 75 cm apart, and seed planted at rates to insure one plant every 6 to 12 cm of row. Where seedling emergence may be hampered by heavy soil, the seeding rate should be increased, and the desired stand of plants achieved by thinning after emergence. Five kilos of seed should plant one hectare.

Weed Control

The principal need for tilling sesame is for weed control. Sesame is not easily smothered by weeds, but their presence will reduce yields because of competition for soil moisture and nutrients. Weeds should be removed while still small to avoid competition with sesame root systems. Pulling, hoeing, or cultivation when weeds are larger reduces yields. If other methods of weed control cannot be done on a timely basis, it may be necessary to use a selective herbicide that will kill the weeds present without damage to the sesame.

(NOTE: No recommendations are made on treating seeds before planting, since such treatments are poisonous to man if surplus seed is eaten; and must follow the in-country regulations. Extreme care should be exercised in the use of chemical herbicides and insecticides. Applications of such chemicals late in the growing season may cause chemical residues to appear in the seed making in commercially unacceptable.)

Disease Control

Frequent rains and high relative humidity may produce disease outbreaks on sesame. In climates of moderate to limited rainfall, disease prevention is feasible by two practices: (1) growing strains or varieties that are resistant to locally prevalent diseases, and (2) field sanitation. Field sanitation should include crop rotation so that sesame is not grown on the same field in successive seasons, and also the removal of all crop residues after harvest. These practices greatly reduce the disease hazards, and disease control should not be important in drier climates suitable for sesame.

Insect Pest Control

Prompt planting at the very beginning of the rains after a dry period, will evade many or most of the insect problems. There are two other preventive measures that should be invoked: (1) plant strains or varieties that have resistance to the prevalent insect pests, and (2) remove all residues immediately after harvest. These practices, combined with early planting, will reduce insect damage. However, whenever specific insects multiply to the point of serious injury, an insecticide that is toxic to the species should be applied. Prompt treatment is most likely to be effective. In general, sesame is not seriously damaged by insect pests.

Harvest and Threshing

Varieties differ in length of growth period, from 85 to 150 days. Harvest should be made promptly, as soon as the first pods (capsules) begin to burst, to avoid seed loss. The plants should be cut off at ground level (or pulled), tied in bunches or sheaves, and stacked upright in shocks to complete drying. When all of the pods in the shock have burst open at the tips, the sheaves are carefully inverted over a canvas or threshing floor, and the seeds fall out without flailing. The crop is cleaned by screening and winnowing of the seed. If grain combines are available, threshing can be done with them by going from shock to shock.

With seed moisture content at 10% or lower, there should be no molding in storage.

Storage Insect Pest Control

Stored grains and seeds are always subject to insect damage in the tropics unless properly treated. All empty storage structures and containers should be treated with malathion or other effective insecticide before being filled, to kill insects harbored in them. The seed should be fumigated as it enters storage, to kill insects brought in from the field. Further fumigations should be made, if subsequent insect infestations occur. For further discussion on fumigation, see the Chapter on Maize, section on storage insect pest control.

Footnote: For further information on Crop Protection, see Chapter 4 in book on "Tropical Agriculture" by Wrigley, (Reference list following Chapter 40).

CHAPTER 23

SUNFLOWERS [1/]
(*Helianthus annuus*)

Geographic Distribution

Sunflowers are a relatively new crop to most areas of the world, although they have been grown as a major source of oil in the Eastern European countries for several decades. Sunflowers, like maize, are a native plant species to the North American continent and are presumed to have evolved in the southwestern United States or on the plateaus of Mexico. Sunflowers were introduced in Europe in the 18th Century and later to the Soviet Union. Scientists in the Soviet Union realized the adaption of sunflowers to their particular ecological conditions and pursued an energetic and most successful program of varietal improvement.

At present sunflowers constitute the second most important oilseed crop (following soybeans) in world production. World production is much greater in temperate zone countries than in the tropics. Temperate zone production is greatest in Argentina, Bulgaria, Romania, Yugoslavia, U.S.S.R., and Uruguay where production of sunflowers in the tropics and subtropics is in Ethiopia, Morocco, Tanzania and Turkey where they are usually grown as a major crop in rotation with maize, sorghum and millet, and in competition with such crops as groundnuts, and the food grain legumes. Sunflowers are about as tolerant of heat and drought as sorghum and millet. Sunflowers are apparently well adapted to all tropical and subtropical savanna regions; being responsive to sunny weather, intermittent rainfall, moderate to low relative-humidity, and a wide range of soil conditions. Improved varieties have been developed for the temperate zone countries but few varieties have been developed specifically for tropical agriculture. In all areas of production the crop is utilized both for direct consumption as food, and for oil and oilseed cake that enters trade in competition with the products of other edible oilseed crops. Sunflower seed yields range from over 2000 kg/ha in Yugoslavia to as low as 350 kg in some tropical countries. It is probable that yield potentials in tropical countries will more nearly equal those in temperate zones when comparable technology, and adapted varieties are developed.

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Sunflowers can be utilized effectively for subsistence, or as a cash crop. They may contribute to domestic market demands, or serve as an export crop (seed, oil and cake). European countries import about 85% of the crop that enters world trade channels, and Asian countries about 15%. Sunflower oil is a semi-drying oil (like soybean oil) and may be used either as an edible oil or as an industrial oil.

Sunflower Seed as A Food

Sunflower seeds are eaten as salted whole seeds, and as roasted nut meats (dehulled). The crop may be processed for oil extraction by using seed with or without hulls. The cake containing hulls is excellent feed for ruminant livestock; and the cake and meal produced by processing dehulled seed is an excellent protein food in human diets. Commercial processing of a metric ton of seed for oil yields roughly about 400 kilos of oil, 350 kilos of meal, and 200 kilos of hulls per metric ton. The average compositions of the whole seed, dehulled seed and of sunflower meal are as follows:

	Protein (%)	Oil (%)	Carbohydrate (%)	Mineral Matter (%)
Whole seed (with hulls)	20	46	25	4
Naked kernels	24	55	12	4
Meal (from dehulled seed)	50	4	36	8

Sunflower protein is superior to most vegetable proteins and equal to soybean protein in terms of digestibility and comparable in biological value. Sunflower protein is more nearly balanced in essential amino acids than most other vegetable proteins. While being slightly deficient in lysine, the net dietary value of sunflower protein is 93% as high as the standard egg protein used by nutritionists. Soybean protein rates 62% and ground nut protein 69%.

The sunflower seed and meal are high in calcium, phosphorus and iron that are essential in human diets. The contents of the vitamins-thiamine, riboflavin, and niacin are also quite high.

The oil is used for cooking, fuel in oil lamps, and for manufacture of margarine and food dressings.

Classes of Sunflowers

There are two distinct classes of cultivated sunflowers, an oilseed class and a confectionery or garden class. Varieties in the oilseed class are characterized by smaller and darker seeds of higher oil content and lower hull content than the varieties in the confectionery or garden class. The hull of the confectionery varieties is heavier and does not adhere as tightly to the kernel, thus allowing for easy decortification. In the western world, varieties in the oilseed class are used exclusively for oil extraction, whereas the confectionery varieties are used primarily for salting or as a source of nut meats for roasting.

Adaptation

Sunflowers are best adapted to savannah climates, and may be damaged by diseases when grown in high rainfall areas. The crop is well suited to tropical zones, since it is not particularly sensitive to changes in day length; the sequence of vegetative growth, fruiting and ripening proceeds in normal sequence in all latitudes. It thrives in the entire range of climates suited to maize, sorghum, and millet. When sunflower plants are well-established they tolerate a considerable amount of drought and heat, with prompt recovery when rains occur. Sunflowers have considerably more frost tolerance than maize, sorghum, and millet, especially in the seedling stages. Consequently, sunflowers can be grown in climates where occasional low temperatures seriously damage maize, sorghum and millet.

Sunflowers grow on a wide range of soils, but prefer rather deep soils with good water storage capacity. They are believed to be tolerant of soils low in fertility; and are somewhat tolerant of saline and alkali soils that are more common in drier regions. Since sunflower seed is high in protein and minerals, it is logical that high yields require substantial amounts of fertilizer to correct soil deficiencies.

Description

Sunflowers belong to the genus *Helianthus* which is composed of nearly 70 species of both annual and perennial habit. Of the annual species only cultivated sunflowers, *H. annuus* have played an important role in agricultural production. Nevertheless several of the other species may serve as valuable germplasm sources for improving the cultivated types. Cultivated sunflowers are for the most part single headed, producing heads (discs) of aggregated fertile flowers, bordered by sterile ray flowers that are lemon yellow to orange in color. The plant is a stout, erect annual, with most varieties ranging from 1.5 to 3 meters in height. The stems are rough and hairy. The plant has rather large pointed leaves borne on short petioles, rough and hairy overall. The discs (heads) may vary from 10 to 30 cm in diameter depending upon the variety and the plant population. Flowers are almost completely cross-pollinated by insects but under favorably environmental conditions considerable selfing may occur. The seed is technically an achene, consisting of an embryo entirely encased in a fairly tough pericarp.

Sunflowers have a tap root system which is well branched and extends laterally for several meters and makes good use of available moisture in the upper soil profile. However, they do not penetrate and remove water as deep from the soil as many other tap rooted crops.

The plant takes the name "sunflower" from the bending of the stem (nutation) so that head and leaf positions follow the sun during the daylight hours, facing east in morning, the zenith at midday, and west in the evening. This following of the sun partially ceases after pollination when the heads remain oriented towards the east. Advantage can be taken of this movement when the crop is to be hand harvested, by planting rows north and south, so that harvest of heads is facilitated by cutting the overhanging heads on the east side of every row.

Varieties

Since sunflowers are highly cross-pollinated, there is much variability within most varieties. Selections for specific traits - height, length of growing period, disease resistance, seed color and size, stem branching and head size, etc. -have produced varieties that are relatively distinct. Until rather recently, the development of oilseed varieties was concentrated in the U.S.S.R. and Southeastern European countries where significant progress was made towards the development of high-oil high yielding varieties. Breeding programs aimed at developing both superior oilseed and confectionery varieties are now also in progress in Argentina, Canada and USA.

The recent discovery of cytoplasmic male sterility and fertility restoration in sunflowers has paved the way for the efficient production of first generation hybrids much like that of hybrid maize and sorghum. The United States have pioneered the development of hybrids sunflowers via this route and several hybrid varieties are now available in the U.S. that offer greater uniformity, higher oil, higher yield, and greater disease resistance than the previous open-pollinated varieties.

The Soviet varieties, including Peredovik, Sputnik, Smena, Armavirsky, Krasnodarets, Armaveric, VN11Mk 8931, which make up the bulk of the present world wide acreage are produced by open pollination, but with continuing selection to maintain type and yielding ability. Unlike the hybrid varieties the older open-pollinated varieties have a wider ecological adaptation and perform better under widely diverse conditions than do hybrid varieties. The variability existing in sunflowers, however, suggests that hybrids can be developed and regionalized to fit most any specific ecological condition.

Countries that wish to grow sunflowers as an important crop should assemble seed of as many open-pollinated and hybrid varieties as possible for field testing under conditions representative of the area where the crop is to be grown. All varieties should be tested and grown with cultural practices designed to produce high yields.

Culture

Fertilization

Fertilizer requirements of sunflowers are generally similar to those of maize and sorghum. Nitrogen is a first requirement, followed by phosphate. Potash is a requirement in regions of moderate to good rainfall, but may not be required in drier zones. A preliminary evaluation of responses to nitrogen fertilizer should begin with the equivalent of 100 kg of N per hectare. Nitrogen fertilizers may be broadcast, or applied with the mineral fertilizers. Subsequent tests should use nitrogen fertilizers in graduate higher amounts to determine optimum amounts.

Phosphate and potash fertilizers should not be broadcast, but applied in bands placed below the seed. Mixing phosphates through the soil mass often produces little benefit on tropical and subtropical soils, because these soils promptly interact with the phosphate to make it inert. Positioning the phosphate in bands under the seed largely prevents the undesirable interaction, and insures a nutrient supply to the plant, from early germination onward. A practical method of banding phosphates (and potash) is to open a shallow furrow, place the fertilizer in the bottom, cover with 5 to 8 cm of soil, place the seed thereon, and cover with 2 to 4 cm of soil. Such placement may also be done by machines at planting time. For perliminary evaluation of mineral fertilizer needs, it is suggested that the equivalent of 50 kg/ha of P_2O_5 and 25 kg/ha of K_2O be spread. Subsequent trials should be made with increasing amounts until the optimum rate is determined. Sunflowers have a reputation for being able to feed on soil minerals not readily available to other crops, so conclusions as to fertilizer needs for maize and sorghum are not directly applicable to sunflowers.

There is no specific evidence as to "trace" element deficiencies affecting sunflower yields, but this possibility warrants attention since failure to get responses to fertilizers may be controlled solely by trace element deficiency. The trace elements are manganese, iron, copper, zinc, boron, and molybedenum. Until such time as experiments have identified the specific deficiencies on major soil groups, it is suggested that animal manures be used as a source. Most manures carry these elements in small amounts in forms available to plants. A practical approach would be to spread dung in the furrow with the phosphate, or to spread it in the bottom of a plowed furrow during seed bed preparation, approximately under the proposed location of the plant row. This method conserves supplies of dung that are usually in short supply.

In supplying phosphate, it should be noted that ordinary superphosphate also contains enough calcium, manganese, and sulfur to satisfy most crop needs. However, concentrated superphosphate and ammonium phosphate do not contain sulfur, and this must be provided separately if needed.

Seed Bed Preparation

Sunflowers require seedbed preparation similar to that for maize. All growing weeds should be killed, trash and crop residues removed or turned under, and larger clods broken up. The soil should be moist and reasonably mellow to ensure prompt germination.

Planting

In regions with a limited rainy season, planting should be done immediately before or as soon as rains begin, to fully utilize the rainfall and to evade possible insect damage. Varieties should be selected that will fully utilize the rainy season, but mature after the dry season begins. Varieties of several maturity classes are available to choose from. Seed should be planted 5 to 8 cm deep, in rows 50 to 100 cm apart, at rates to produce one plant every 20 to 30 cm in the row. Wider or narrower spacings may be made to adjust to rainfall expectancy, wider spacing in area of low rainfall and narrower spacing in areas of high rainfall. Three to six kilos (depending on seed size) of sound seed should plant one hectare. (NOTE: Recommendations on chemical treatments for seed are not made here, because such chemicals may be toxic to man if surplus seed is eaten, and the treatments must comply with country regulations.)

Weed Control

Weed control is important in production of higher yields of sunflowers, particularly in regions of limited rainfall, since weeds use moisture and nutrients that would otherwise be utilized by the sunflower. Weeds should be removed while still small, to minimize competition with the crop, and to avoid unnecessary damage to the sunflower root system. If prompt removal is not feasible, it may be desirable to use a selective herbicide that will kill the species of weeds present without injury to the sunflowers. Several selective herbicides are available, some applied before planting and incorporated by cultivation and some applied on the soil surface immediately after planting.

Insect Pest Control

The depredations of insects can not be predicted for wide areas, but certain preventive practices are generally effective. (1) Plantings should be made promptly at the beginning of the rainy season to minimize insect damage. (2) Select varieties that have shown resistance to insect damage in field trials within the region. (3) Practice field sanitation by removing plant debris soon after harvest and destroy volunteer seedlings.

When serious insect infestations are noted, control measures should be promptly applied to prevent rapid increase in numbers of insects. The insecticide chosen should be toxic to the specific insect, and used as prescribed on the insecticide container. (See footnote on Crop Protection)

Footnote: For further information on Crop Protection, see Chapter 4 in book on "Tropical Agriculture" by Wrigley, (Reference list following Chapter 40).

Disease Control

Sunflowers are particularly vulnerable to attack by several disease producing organisms. Diseases frequently are more severe in areas where sunflowers are intensively cultivated. Normally, diseases are not limiting factors to successful sunflower cultivation the first few years of production. A major factor in disease attacks on sunflowers is that for the most part, diseases are aggravated by abundant rainfall and high humidity. The crop is not well adapted to regions where these conditions prevail. Disease control need not be difficult in drier regions if sound pest management practices are followed. To minimize losses from diseases the following practices should be followed. (1) Plant only high quality disease free seed. (2) Avoid planting sunflower in rotation with other agricultural crops that are susceptible to charcoal rot, verticillium wilt, and white mold. (3) Avoid planting sunflowers on poorly drained soils that are subject to waterlogging. (4) Use a crop rotation such that sunflowers are grown on the same field only once every 4 years. (5) Remove crop residue as soon after harvest as possible. (6) Destroy volunteer plants soon after they emerge. (7) Plant disease resistant varieties if available.

Bird Damage

Ripening sunflowers may suffer from bird damage. If the seeds are filled, prompt harvest is a possible remedy. However, premature harvest must be accompanied by special drying precautions to bring moisture content of seed down to about 10% to reduce danger of molding in storage. Bird depradation can be minimized by avoiding planting sunflower near nesting, roosting, or watering sites. Bird damage is frequently more severe in small plantings than larger ones.

Harvest and Storage

Sunflowers are mature when the backs of the heads are yellow and the outer bracts turn brown. Seed curing may take place on the standing stalk, if bird damage is not imminent; but harvest must occur before the heads begin to drop on the ground. If harvest is required before seed is completely dry, the heads must be placed in thin layers on open drying floors with occasional turning when moisture is reduced. Large headed varieties are frequently cut by hand; but both larger headed or smaller headed types may be harvested by field combines.

The dried heads may be threshed by hand, by abrasion on a rough or slatted threshing board, or by a threshing machine. All chaff and foreign matter should be winnowed out at threshing time to avoid molding and to eliminate contaminating external insects.

Storage Insect Pest Control

Depradations of storage insects are inevitable in warm climates, unless suitable precautions are taken, similar to those employed for protection of other grains and seeds. All empty storage structures and containers should be treated before being filled, with malathion or other appropriate insecticide. The incoming grain should be fumigated to kill all insects brought in from the field. Careful inspections should be made of the grain during storage for evidence of new infestations and additional fumigation given as needed. For further details on fumigation, see the Chapter on Maize, section on storage insect pest control.

CHAPTER 24

SAFFLOWER 1/
(*Carthamus tinctorius*)

Geographic Distribution

Safflower is an ancient food and edible oil crop, grown primarily in Asiatic, Mediterranean, and North American countries where the climate is semiarid. It is a member of the Compositeae family of plants, distantly related to the sunflower, but different in many respects. World production data are fragmentary.

In North America, the USA, Canada and Mexico have sharply increased total production in recent decades, and production now totals 400,000 metric tons per year. The Old World traditional producers of safflower totaled only 250,000 metric tons, with India, Turkey and Spain leading. However, the production of safflower as a subsistence crop throughout the dry regions of the Mediterranean, Asia and Africa does not enter into statistical reporting. Only when family or village production is fortunate enough to exceed local needs does the surplus enter into trade channels. This type of production usually does not attract the attention of leaders in agricultural development, so that culture of safflower has not benefited from modern science and technology in the Old World regions. However, safflower production in North America has now demonstrated that farm production may easily reach levels of 2800 kg per hectare with improved varieties and suitable cultural practices. Safflower appears to have substantial undeveloped potential as a cash crop.

Utilization

Safflower is used for food and as a source of edible oil. Safflower is grown as a short-season crop in regions with short rainy seasons, using varieties capable of completing growth and maturation before soil moisture is exhausted. It is also planted following a major crop, to utilize relatively short periods when moisture supply may be adequate. The potential productivity of safflower on irrigated lands in the southwestern United States has been evaluated; and it appears to be at least equal to wheat and barley in net value of the crop per hectare.

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Safflower seed averages 40 to 55% hulls, with smaller hull percentages on seed produced with improved varieties under favorable moisture conditions. The oil may be extracted from whole seed, or from dehulled seed. Oil content ranges from 22 to 42%. The meal derived from the naked kernels (dehulled seed) averages 42% protein; and the cake produced by extraction of oil from the unhulled seed averages 21% protein.

The oil is a significant product of safflower; it is used for cooking, as a foodstuff, for making food dressings, and for lighting. It is processed to make margarine, and for nearly all other uses to which sunflower oil is put.

The cake produced by pressing oil from unhulled seed is an excellent feedstuff for ruminant livestock and for horses, mules and asses; and the meal from naked seed is an excellent high-protein foodstuff for man.

Safflower as a Foodstuff

Safflower seed may be roasted whole for eating out of hand, or the seed may be roasted after dehulling. The naked meats may be home-processed in many ways for direct consumption as food, and the oil content gives them a high caloric value. Roasted nuts may be processed for oil, which yield meal having a total protein content of 42%. Safflower protein is somewhat deficient in the essential amino acids - methionine and cystine. Safflower meal (and the whole naked meats) constitute a useful "extender" of animal proteins (meat, milk, eggs, fish) wherever the animal proteins are in short supply. Safflower seed will supplement human diets that are high in cereal grains; and the oil meets dietary needs as well as being used for home lighting.

Adaptation

In general, safflower is best adapted to semiarid regions where it is grown in the short seasons when rainfall is likely to be adequate for crop production, and in irrigated fields in such regions. Safflower suffers severely from diseases in humid regions. However, it grows well in regions of monsoon climates, as a crop planted at the waning of the rainy season, that makes its growth on stored soil moisture, and matures in the following dry period. The best yields are made when the weather is warm and low in humidity during the blooming period, but with adequate soil moisture still present. Depending on the variety, the average growth period ranges from 3 to 5 months.

The crop prefers soils of average to good fertility. However, soil depth and soil water storage appear to be more important than soil fertility in the climatic region where safflower is grown successfully. When moisture is not limiting, safflower usually responds to fertilization, particularly nitrogen and phosphorous.

Description

Safflower is a member of the Compositeae family of plants. It is an annual, erect herbaceous plant that grows 30 to 90 cm tall, depending on the variety. The stems are pithy, branched toward the top, with flower heads at the end of each branch. The globular heads are thistle-like, 1½ to 4 cm in diameter, with white, yellow, orange or red florets. The leaves and the bracts below the flowers have short spines. The safflower seed resembles a small sunflower seed, and is smooth, 4-angled, white or cream colored.

The root system is a strongly developed tap root with branches, that makes effective occupation of the soil profile to depths of about a meter on permeable deep soils, that are moist to that depth.

Varieties

There are many strains and varieties of safflower grown in the Mediterranean, Asian and African regions. The breeding of improved varieties in North America has been based on these Old World strains, but important improvements have been made. Improved varieties are now available with higher yielding ability and oil content, varying plant height and length of growing periods, and disease resistance. Field trials should be made of available improved varieties for each region where the crop is to be grown, to identify those that are best adapted to the conditions at hand. Safflower flowers are cross-pollinated by bees; and the purity of a strain or variety must be maintained by growing seed fields in isolation from other varieties, and removal of off-type plants. The occurrence of unusual plants in field plantings has been used as a means of finding promising strains that are worthy of seed multiplication and testing. However, a serious plant improvement program should begin with a field evaluation of all available types from other safflower growing regions, and the use of the superior types for a breeding program. Some spineless breeding lines are available.

Culture

Safflower does not compete strongly with weeds, and the crop is usually planted in rows to facilitate weed control. The seed bed should be mellow and firm, prepared so that planting may be made promptly when soil moisture is favorable.

Fertilizers

Where soil moisture is adequate, from rainfall or irrigation, the use of fertilizers carrying nitrogen and phosphorous should substantially increase yields. The amounts of fertilizer must be determined by field trials; but initial trials may begin by supplying 50 kg of nitrogen (N) and 50 kg of phosphate (P_2O_5) per hectare.

Since the phosphate may be inactivated if mixed through the soil mass, it is recommended that the fertilizer be placed in bands below the seed. For hand planting, band placement of fertilizer may be done by making a shallow furrow, spreading the fertilizer, covering with 3 to 5 cm of soil, dropping the seed thereon, and covering the seed with 2 to 3 cm of additional soil. In relatively dry climates, the nitrogen fertilizer will not be leached away, so that both nitrogen and phosphate fertilizers may be applied together in the band. There is not likely to be a shortage of potash in soils of subhumid and other low-rainfall areas.

With some soil types found in dry climates, there may be a deficiency in one or more of the essential "trace" elements that are essential for plant growth. These elements are iron, manganese, copper, zinc, boron, and molybdenum. Research is needed to determine if any of these elements are deficient, on any of the soil groups of a region. However, a simple field test may give an indication as to whether the problem exists. It is suggested that animal manure be added in the furrow with band placement of fertilizer, since manure usually carries a limited amount of trace elements in a form available to plants. If the manure addition produces stronger plant growth than fertilizer applied alone, there is a strong probability that the soil is deficient in one or more trace elements.

Planting

The crop may be seeded in rows 70 to 90 cm apart, at a seeding rate to produce at least one plant every 10 to

15 cm of row. This requires about 20 kg of seed per hectare. Plant populations should be adjusted to provide somewhat greater spacing for larger varieties.

Weed Control

Weeds should be removed before they become large enough to compete with safflower plants for moisture nutrients. (See sunflowers)

Pest Control

Safflower usually is relatively free of diseases in dry climates, and the use of disease resistant types may provide all the protection needed. Insect pests may become a problem in some situations. Insect attacks should be halted promptly whenever they threaten to be serious, by application of an insecticide known to be effective on the particular insect. (See footnote on Crop Protection).

Harvest

The crop is ready to harvest when the seeds are hard and dry. Usually the crop suffers little or not at all from lodging, from seed shattering, or bird damage. Thus, the crop may be allowed to stand in the field until the grain is dry enough to store without danger of molding. Moisture content of the seed should be lower than 10% for safe storage. Threshing is handled much as for barley or wheat, except that the spines make hand threshing quite troublesome. Spineless types are being bred to eliminate this difficulty.

Storage

Safflower seed should have less than 10% moisture content for safe storage; which is a level easily achieved in the drier climatic regions where the crop is best grown. Protection from storage insect damage requires positive action. All empty storage structures and containers should be treated with malathion or some equally effective insecticide to destroy insects that are usually present, before being

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Footnote: For further information on Crop Protection, see Chapter 4 in book on "Tropical Agriculture" by Wrigley, (Reference list following Chapter 40.)

filled with grain. The seed should be fumigated as it enters storage, to kill insects brought in from the field. Periodic inspections should be made during storage and the seed again fumigated whenever infestations occur. For more information on fumigation, see the section on storage insect control, in the Chapter on Maize.

CHAPTER 25

CASTOR 1/
(Ricinus communis)

Other Common Names: castorbean, castor bean, castors

Castor is not a true bean; it belongs to the Euphorbiaceae family of plants. It is not a food crop. Neither the raw seed nor the oil pressed from it is edible. The oil is edible after it has been detoxified by heat, i.e., castor oil is taken internally as a medicine. Castor is included in this Guide because it is a useful cash crop in field rotations where the primary emphasis is on food crops.

Geographic Distribution

Castor is believed to be a native of East Africa, but the wild forms also occur in the Indian subcontinent. At the present time, commercial production is distributed as follows:

Region	Area (hectares)	Major Countries
Asia	473,000	India, Pakistan, Thailand
South America	277,000	Brazil, Paraguay, Ecuador
USSR	200,000	Southern Subhumid regions
Mainland China	180,000	Subhumid regions
Africa	96,000	Ethiopia, Sudan
North America	36,000	USA, Mexico, Haiti
Europe	25,000	Roumania

The major cash markets for castor and castor oil are Western Europe, Japan, and North America. Total imports by countries in these regions amount to about $70 million (US) annually. Producers in the tropics and subtropics appear to be economically competitive with those of the temperate zones, even though the benefits of improved technology have not been exploited in the tropics and subtropics.

1/ R.E. Stafford, Research Leader, Agricultural Research Service, U.S. Dept. of Agriculture, in cooperation with Texas A&M University, Agricultural Research and Extension Center, Vernon, Texas 76384 and B.E. Caldwell, Staff Scientist (Oil Seeds) National Program Staff, Agricultural Research Service, U.S. Dept. of Agriculture, Beltsville, Maryland 20705

Utilization

The castor crop is grown primarily for its oil content. A process has been developed by the U.S. castor industry in which the pomace or meal is detoxified and used as livestock feed. Feeding trials have shown that castor meal compares favorably with other commonly used protein supplements. The oil is a non-drying type that is readily modified by chemical treatment. It has a constant viscosity at high temperatures and thus is useful as a lubricant for machinery under those conditions. Modified castor oil is used in paints and varnishes to increase its quick drying properties. Castor oil and its derivatives also are used in hydraulic fluids, plastics, asphalt tile, certain explosives, electrical insulation, cosmetics, biodegradable detergents, nylon and other synthetic fibers, urethane, and as a purgative for man and animals.

The practices of exporting whole castor from producing countries should be replaced by extraction of the castor oil in the regions where the crop is grown and the cake that is residual from extraction of oil from the seed is used as an organic fertilizer. The oil is more economically transported than the seed, and the cake yields very little cash return. However, the cake (castor pomace) is an important agent for conditioning fertilizers, and it is also a useful source of "trace" elements in regions where there is a deficiency of these in the soils. Granulated castor pomace may be used directly as a fertilizer, or mixed with commercial fertilizers.

Castor pomace averages 5.4% nitrogen, 1.8% phosphate (P_2O_5), 1.0% potash (K_2O), and 0.75% lime oxides (CaO + MgO). The nitrogen is present in a slowly available organic form that is particularly useful in tropical soils. The phosphate appears to be substantially higher in effectiveness as a fertilizer than the same amount of phosphorus in chemical fertilizers.

An approximate value may be placed on castor pomace, by calculation from the market prices of whole seed and of the oil. With an average oil content of 45%, and with the seed priced at $160 per metric ton and the oil priced at $290 per metric ton, the pomace should have a value of $40 per metric ton. Very little net return is now received for the pomace when growers ship whole seed. The true value for castor pomace should be determined by the field performance of the pomace as a fertilizer for crops, in comparison with results obtained from chemical fertilizers alone or when processed for use as a livestock feed.

Adaptation

Castor grows over a wide range of climatic conditions, but it prefers drier climates. In humid regions, the plants are affected by molds that destroy the flower clusters and thus reduce yields. In monsoon wet-dry climates, the crop is planted toward the end of the rainy season, and produces a crop largely on moisture stored in the soil. In general, castor produces well in subhumid to moderately humid regions, and under irrigation in arid regions.

Castor prefers a well-drained soil, preferably loam in texture, but grows well on many other deep soils. It responds reasonably well to improved soil fertility but is less dependent on fertilizers than many other crops. Yields are more dependent on soil moisture content than on other soil properties. It is tolerant of mildly saline or alkali soils.

Description

Castor is actually a short-lived perennial in the tropics and subtropics; but in most commercial production it is handled as an annual crop. Specific varieties grow 2 to 4 meters tall, but the shorter dwarf-internode types are preferred because of the greater ease in harvesting. The leaves are large, 10 to 30 cm wide, and may vary in color in different varieties from green to purplish or reddish. The greenish-yellow flowers have no petals, and are borne in clusters (a raceme). Blooming is indeterminate, and new clusters and ripe seed occur on the same plant. Varieties have been developed in which blooming is concentrated in a short period, so that ripe seed can all be harvested in a single or few pickings. Pistillate flowers (seed forming) are borne in the upper part of each raceme, and staminate flowers (producing pollen) in the lower part.

The plant is largely cross-pollinated, but natural selection has produced different types in the various regions where the crop is grown. The seeds are borne in capsules of 1 to 3 seeds each, and the capsules may be spiny or smooth. Wild forms of castor forcibly eject the seeds at maturity, but most cultivated types retain the seed for an extended period, and shattering losses are small. The obovoid shaped seed somewhat resembles a bean, and may be mottled, striped, or a solid color.

The castor plant has a strongly branched tap root, that deeply penetrates the soil. The extensive root system is partly responsible for the plants tolerance of drought.

Varieties

Improved varieties have been developed in several countries to increase seed yields and to establish uniform plant characteristics that facilitate production and harvest such as short plant height and the non-shattering habit. Commercial varieties with these traits have been produced in the United States. It is probable that much additional improvement could be made in the productivity of the crop in all tropical and subtropical regions, by field evaluation of the wide range of improved varieties already available, and choosing those best suited to local conditions. Further improvement could be made by identifying desired traits in plants found in local fields of the crop, and by using these in a well planned breeding program. Resistance to important diseases and insect pests, as well as in yielding ability, are heritable traits, and these characteristics may be strengthened by appropriate breeding methods.

At one time it was believed that smooth capsules might have an advantage, especially in harvesting, but this was later discounted when modern mechanical harvesters were developed. At the present time, there are no commercial U.S. varieties being grown which have smooth capsules, nor any breeding work in this direction. However, breeding lines with smooth capsule characteristics are available to breeders interested in incorporating this characteristic into their improved varieties.

Great differences are reported in average yields of castor in various countries, ranging from 260 to 1250 kg per hectare. There are several factors responsible for such differences, such as natural adaptation to climate and soil, use of improved varieties, and application of modern technology (fertilizers, pest control, etc.) and all of these are partially or wholly under the control of man. Yields of 2500 kg per hectare appear to be feasible, and would greatly enhance net cash returns per hectare. Varietal improvement must be accompanied by effective cultural practices to achieve such returns.

Culture

Fertilization

Although castor tolerates soils of relatively low fertility, the use of fertilizers is recommended to increase yields and make the best use of rainfall. Field experiments to measure responses of castor to fertilizers, are generally absent; but the responses of other crops (maize, sorghum, millet) may be used as an index. Responses should be expected from effective use of nitrogen and phosphates on most soils in regions where castor may be grown as a crop.

The placement of fertilizer in bands below the seed is recommended to insure that the young plant gains access to the fertilizer promptly, and to minimize the inactivation of the phosphate by soil contact, which is an important undesirable trait of many tropical soils. Mixing fertilizer with the soil mass is far less useful than band placement. A practical method is to open a furrow, place the fertilizer in a band in the bottom, cover with 5 to 8 cm of soil, place the seed thereon, and cover the seed with about 5 cm of soil. If field trials have not been made locally to determine an effective amount of fertilizer to use, it is suggested that the equivalent of 100 kg of nitrogen, and 50 kg of phosphate (P_2O_5) be applied per hectare. In humid regions, potash (K_2O) may be added at 25 kg per hectare.

It should be noted that ordinary superphosphate contains enough calcium, magnesium and sulfur to meet the crop needs when this fertilizer is used. However, concentrated superphosphate carries little or no sulfur, and this element must be provided separately if they are deficient in the soil.

On strongly weathered soils of the tropics and subtropics, evidence is being found of serious deficiencies in "trace" elements needed in small amounts by crops. Correction of any such deficiencies is required to permit responses to the traditional mineral fertilizers. One or more of the following elements may be deficient: manganese, iron, copper, zinc, boron, and molybdenum. Until the necessary research has been done on major soil groups to determine specific deficiencies in trace elements, it may be practical to make applications of animal manures which usually contain small amounts of trace elements in readily available form. It is suggested that dung be spread with the fertilizer in furrows, as described above. An alternate method would be to place dung in the bottom of a furrow during plowing, under the intended location of the crop row.

Seed Bed Preparation

The seed bed should be mellow and friable; all living weeds killed, and trash removed or plowed under. The fields should be managed to conserve rainfall by reducing runoff and storing rain in the soil profile.*

Pest Control

Little has been done on disease control on castor since diseases have not been serious in drier climates with low air humidity. A mold disease often destroys flower clusters in humid regions.

The insect problems may become important locally. The specific insect should be identified, and a suitable general purpose insecticide applied promptly to stop the damage and prevent a build-up in numbers.

Harvest

Harvest should begin as soon as seed in the capsules is dry, and continued as additional seed clusters ripen. A satisfactory harvesting method is to hand strip all of the capsules from each fully ripe seed cluster, and collect these in a cotton picking bag. Strong gloves are recommended to protect the pickers hands, since penetration of spines into the skin will cause prolonged inflammation.

The capsules should be dried further, in shallow piles exposed to the sun, until moisture content of the seed falls below 10%. When dry, the seed is threshed by hand flailing, or by special hulling machines. The chaff should be removed by winnowing. Field machines are now available for combined harvest and threshing as a single operation.

Stored Grain Insect Control

If the seed is not processed promptly for oil extraction, precautions should be taken to prevent rapid insect damage in storage. For details on such protection, see the section on stored grain insect control in the chapter on Maize.

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*For further information see Technical Series Paper, No. 4, "Improving Farm Production in Tropical & Subtropical Regions of Limited Rainfall". Feb. 1971, Office of Agriculture, Bureau for Technical Assistance, Agency for International Development, Washington, D.C.

CHAPTER 26

BANANAS [1/]
(Dessert Bananas and Plantains)
(*Musa* spp.)

The term "banana" encompasses a wide range of seedless varieties plus many wild seeded species. The former are generally propagated vegetatively by suckers, while the latter are propagated both vegetatively and by seed. All seedless varieties, except the plantains, when ripe, can be eaten as fresh fruit, and when green they can be utilized for cooking. The main distinction between a dessert banana and a cooking banana is the type and amount of starch granules in the particular variety. For example, the dessert variety, Gros Michel, has small starch grains, and when ripe, has a low percentage of starch; the French Plantain, on the other hand, has large starch granules, and when ripe, contains a high percentage of starch.

There are approximately thirty species and subspecies of bananas, and many hundreds of varieties have been identified to date. Differences in the characteristics of edible banana varieties are due to their evolutionary origin. Only two *Musa* species form the progenitors of the present range of edible varieties. *Musa acuminata* and its subspecies provided factors for sterility, pulp development without fertilization (parthenocarpy), a sweet sugary taste, and susceptibility to drought and low temperatures. *Musa balbisiana* provided large starch grains, general starchiness, drought and chill resistance, and in general, a greater resistance to diseases. Due to a meiotic (sexual division) freakishness of these two species, the natural hybrids that developed were either triploids (having three sets of chromosomes) or pentaploids (having five sets of chromosomes). The latter had too cumbersome a chromosomal complement to survive in nature. Hence, the majority of edible varieties, whether a direct descendent of *M. acuminata* or the result of a natural cross between a subspecies of *M. acuminata* and *M. balbisiana*, are triploids. That is, they have three sets of chromosome numbers, which in the case of bananas, is three sets of eleven chromosomes each. The evolutionary distinction between a dessert banana and a plantain is that in a banana, all three sets of eleven chromosomes originated from *M. acuminata* while in the case of the plantains, two sets of chromosomes came from the *M. acuminata* parent and the third set came from the *M. balbisiana* parent. In botanical terms, the dessert

[1/] Edited by N.G. Vakili, Plant Pathologist, Agricultural Research Service, U.S. Department of Agriculture, Federal Experiment Station, Mayaguez, Puerto Rico 00708 banana is considered a natural inbred variety, while the plantain is a natural hybrid variety.

The tropical mainland of Southeast Asia and the many large islands of the area form the main geographic center of the origin of edible bananas. For example, the original name of the famous Gros Michel banana of commerce is "Pisang Ambon", or "banana of Ambon", which is one of the islands of Indonesia. Also, the Fusarium wilt-resistant and high yielding banana which now covers thousands of acres in tropical America, the variety, Valery, is "Choui ya cui", which had its origin in the lowlands of southern Vietnam in the Mekong Delta. The hybrids came from further west, most likely centered around Burma and Bangladesh. This is because M. balbisiana originated in the Indian subcontinent, and the area where the two species intermingled was the center of the hybrid types.

Banana plants vary in size. In the Cavendish group (dessert bananas similar to each other except in height), the Extra Dwarf Cavendish grows like a giant leaf lettuce on the ground; Giant Cavendish has a height of about two meters, and the trunk of the Giant Lacatan reaches a height of four meters. Among wild species, the differences are much greater. For example, M. rosea, a flowering banana, has a total height of only one meter and a trunk diameter of 5 to 8 cm, while M. ingens reaches a height of 10 meters and has a trunk diameter of 50 to 80 cm.

Food Value and Uses

The edible portion of the banana is about 75% water, 1.2% protein, 0.2% fat, 23% carbohydrate and 0.8% ash. It is also relatively well supplied with calcium, phosphorus and iron, and with the principal vitamins. It is essentially an energy food, and should be supplemented with other foodstuffs that provide protein and fats to provide a balanced human diet. The carbohydrates present in ripe sweet bananas are highly digestible, and are reported to be well tolerated by people suffering from various intestinal disorders.

In various samples of commercially harvested bananas, the green harvested banana has less than 2% sugars and about 20% starch; but the starch is gradually converted to sugars during the ripening process so that the fully ripe banana has about 19% sugars, and less than 2% starch.

In the tropics a banana plant serves many purposes. The trunk is often chopped up and fed to pigs, or in a tree nursery the trunk sheaths are doubled over and used as planting containers. The xylem strands are twisted together and used as ropes. A banana leaf can be cut up and made into small pots for transplanting garden seedlings, serve as a wrapping inside of which food is cooked, and can even be used as an umbrella in case of a sudden rain. The green fruit can be fermented into vinegar and the ripe fruit into rum. The starchy pulp of the green fruit can be dried and made into flour or the ripe fruit can be mashed into a baby-food puree, or cut into chips and dried as figs. There are dozens of different ways that bananas and plantains are mashed, cooked, chipped and fried. The male bud of a number of hybrid varieties is used as cabbage. Man, at whatever stage in his development, makes good use of bananas. In New Guinea, the aboriginal nomads eat the sweet pulp of the wild species and use the seeds as beads. In Central America, 12,000 hectare blocks of a single variety are cultivated under the most modern and mechanized form of management and the product is graded for strict quality-controlled markets.

Cultivation of Bananas

Essentially the same cultural practices are required for both bananas and plantains. In the recommendations that follow, the differences between the two types are indicated as deemed appropriate.

Climatic and Soil Considerations

Temperature - Mild freezes may kill the top growth back to the ground in some regions, but the rhizome if not damaged will send additional shoots up again. This occurs sometimes in the highlands of the tropics and subtropics. Under such conditions, to product fruit within the frost free periods, the planting rhizomes must receive special treatment. All of the eyes are removed except one so that most of the growth from the entire underground parts go to this one shoot which develops a larger stalk and ripens earlier than it otherwise would. Such practice should be used only under special conditions and then it may not be economical.

The average optimum daily temperature for the growth of bananas is about 27°C, the average minimum, 21°C, and the average maximum, 29.5°C. The absolute minimum and maximum temperatures are 15.6°C and 37.8°C, respectively. Exposure to temperatures below and above these absolute temperatures slows down growth and damages the fruit.

Moisture - The optimum amount of moisture required for uniform growth is about 1320 mm of rain per year, or still better, a uniform distribution of 2.5 cm per week. However, seldom, if ever, does such uniform precipitation occur in any tropical region. In some regions, most of the precipitation will occur between the months of May to November, with December and April receiving the minimum requirements of approximately 1.3 cm per week. The months of January, February, and March may be dry, and the banana plants would not receive enough moisture. For uniform growth, and hence, a good yield, banana plantations should be irrigated during these months. If, however, irrigation requirements approach five months out of the year, the cost of maintaining uniform growth becomes excessive, and indicates the need of either a change in variety or a change in crop.

Wind - Banana leaves are large, soft, and easily torn by strong winds which seriously reduce productivity. If natural wind-protected areas do not exist, it is highly important to provide windbreaks for the plantings. The large growing bamboos make excellent windbreaks, while *Leucaena glauca* can be effectively used around small gardens. The ideal location is a protected valley as can be noted by observing growth of local vegetation and the amount of leaf damage in the area.

The majority of banana varieties can tolerate winds of up to 40 kilometers per hour. Winds between 40 to 55 kilometers per hour cause a moderate amount of damage, but winds above 55 kilometers per hour are disasterous and cause "blow-downs", in which a large portion of a plantation can be ruined.

Soil - Bananas require exacting soil texture, moisture and aeration, even though one sees bananas growing on beach sand or heavy clay soil. There is no use to attempt to grow bananas on a profitable commercial basis in soils which lack fertility or are deficient in physical structure. Since bananas are extremely shallow rooted, a deep alluvial soil is necessary. The type of soil best suited for banana cultivation consists of a sandy to silty-clay loam texture. Good drainage is as necessary as a uniform source of moisture.

The root system of the banana plant forms a semispherical zone centering around the rhizome (the underground stem). The radius of this semisphere and its depth depends on the banana variety, the type of soil, and the drainage in the field. For example, the root radius of Dwarf Cavendish may reach 2.7 to 3.1 meters, while that of a Lacatan may reach 4.3 to 5.5 meters. However, if the soil is heavy clay, the radius of these root systems will greatly diminish. Also, if the water level remains 60 cm below the surface, the roots will not extend downward more than this depth, even though the soil may be sandy-loam.

Geographic Areas - The optimum areas in the world for banana cultivation are located in a belt of land straddling 15 degrees north and south of the equator. From 15 to 23 degrees north or south, bananas occasionally may suffer chills which not only damage the hanging fruit, but also slow down the uniform growth of the plants, which causes an increase in the interval between harvests. Between 23 and 30 degrees north or south, bananas become a seasonal crop, with three to five harvests during the warm months and none during the cold months.

Cold and Drought Tolerance - Since elevation in tropical regions greatly affects temperatures, bananas being sensitive to chill should not be grown over elevations of 1,000 meters as a general rule. Then only the subtropical Dwarf Cavendish, sometimes called Chinese Dwarf. Many of the plantains known largely by their local names such as French Plantain, and Horn Plantain have much greater tolerance to both drought and chill and all plantains have considerable tolerance to drought. In the mountains of South East Asia, such varieties as Lady Finger and Morang Datu are sometimes cultivated up to 3,000 meters elevation. In general, it is wise to use only the dessert bananas of the short stature varieties at the higher elevations. All sizes of dessert bananas can grow easily between the equator and 15°N and S., but between 15 to 23°N and S., it is better to choose varieties with intermediate stature, such as Giant Cavendish, Bout Rond, Vimama, etc. Beyond 23°N. and S., it is best to cultivate Dwarf Cavendish.

The only known exception to the above is the giant wild species *M. ingens* which is encountered at elevations of 1,500 to about 2,440 meters on Mount Cyclope in northern New Guinea. The seedlings of this species fail to grow under hot tropical lowland conditions.

Planting Methods

The edible banana varieties do not produce seeds. The dark, small specks in the central portion of the banana fruit are the aborted ovaries which, even when pollinated, fail to develop into seeds. Hence, bananas are propagated vegetatively by means of transplanting rhizomes, or seed-pieces or "sword suckers" 50 to 60 cm tall which bear only long narrow leaves.

Size of Suckers or Seed Pieces - It is important to select uniform seed pieces. The best size for transplanting is known as a 'maiden head' sucker which is from 1 to 1¼ meters tall and from a plant which has not yet borne fruit, and the seed piece weighs 2 to 2.5 kilograms. If a farmer plants a field of 2.5 kg maiden heads, he can expect first fruiting of a crop in about eight months after planting date. If "sword" suckers, those with vary narrow leaves, 0.5 kilograms in weight, or corm pieces (underground part supporting old trunk which has fruited) containing one eye are planted, a much longer time is needed to produce marketable fruit. If seed-pieces of different sizes are planted, the planning for uniform cropping becomes disrupted.

Preparation of Seed pieces for Transplanting - After a seed-piece is dug up, all soil, roots and trash should be completely removed. If purplish or reddish nematode lesions are detected on the roots, these should be pared off along with any dark and reddish tissue, until the seed piece is clean and white leaving a few buds. Damage from nematodes may be reduced by dipping the planting material in a nematocide. The "cabbage" or top growth should be cut back to about 10 cm from the growing tip of the rhizome. The common practice among small farmers is to retain the trunk of the transplant, although it serves no useful purpose except as a marker. There are no roots to furnish nutrition or water for the trunk. The trunk shrinks and the new leaf grows slowly. Also, the weight of the trunk makes shipment and transportation difficult and expensive.

The Planting Hole - The transplanting hole should be large (75 cm square) and about 15 to 20 cm deeper than the height of the rhizome with its cabbage. Place about 10 grams of complete formulation of an N-P-K (nitrogen-phosphorus-potassium) fertilizer, plus a few grams of a granular nematocide in the bottom of the hole. It is also desirable, particularly on less fertile soil to cover seed with a heavy application of compost and soil. A good thick layer of mulch greatly enhances recovery and continued growth of the seed piece. The soil around the seed piece should be well compressed and irrigated. The best time for planting rainfed bananas is the beginning of the rains, although with a continuous supply of ground water any time of the year would be satisfactory.

Planting Distance

The planting distance between hills depends primarily on the size or the height of the variety cultivated. Also, the type of soil, the amount of fertilizers applied, and the pruning practices determine the proper planting distance for a given variety. The variety Dwarf Cavendish (1 to 1.25 meters tall) can be planted in rows at a distance of one meter within the rows and two meters between the rows. The variety Giant Cavendish (2 to 2.25 meters tall) can be planted in 2.5 x 2.5 meter squares, while the variety Lacatan (about 4 meters tall) should be planted in 3.5 x 3.5 meter squares. The deeper the soil, the closer can be the planting distance for a variety, as long as excessive shading does not occur.

Fertilization

Bananas need fertile conditions and abundance of soil moisture for best growth and production. The type of development the plant makes in the first 3 or 4 months determine the weight of the bunch and number of hands.

The N-P-K formulation to be used depends on the type of soil. Since commercial plantations are usually located on excellent alluvial soils, usually very little P or K are required. The main nutrient requirement is nitrogen, which is generally applied in the form of urea.

The amount of fertilizer used depends on the number of mats per hectare; about 600 kilograms of nitrogen per hectare per year is an appropriate estimate for a deep alluvial soil. If there are 1,000 mats per hectare, then each mat receives 600 grams of nitrogen per year.

Fertilizer should be applied in a circular band around the mat. After planting a seed-piece and up to three months after emergence, the band should have a radius of 50 cm. The radius should be enlarged as the plant matures. The radius of the fertilizer placement around mature mats should be between 1 to 1.5 meters.

On the average, a plantation should be fertilized about every sixth week. During the rainy season, this interval could be reduced to five or even four weeks, and during the dry season might be increased to seven or eight weeks. If fertilizer is applied on the six-week cycle, then each mat will receive about nine 70-gram applications of nitrogen per year.

Growth Pattern

After a rhizome is planted, roots grow out, anchoring the plant in the soil. Leaves begin to grow from the central nodes on the rhizome, and finally emerge from the soil. The leaves consist of leaf sheaths which form the trunk of the banana plant, and the leaf blades which are connected to the sheath by the leaf stem or petiole.

Depending on the variety, a banana plant develops between 30 to 60 leaves before fruiting. Some of these leaves have already developed on the sucker before it is cut off to become a new plant. If a variety produces 45 leaves before shooting (emergence of the fruit bunch), and the maiden head suckers were cut at the 15th leaf stage, then the new transplants would produce the additional 30 leaves before shooting.

The banana fruit forms on the upper nodes of the true stem, which pushes up the length of the trunk until it emerges at the top. At this stage, a plant has "shot" its fruit. The individual banana fruit is called a "finger", and the two rows of fingers, located at each node on the stem, are called a "hand". The whole stem, with its many hands, is referred to as a "bunch".

A "button" is located in the middle of each rhizome node, and is covered by the leaf sheath. When the leaf dies, and the leaf sheath rots away, the "button" grows out of the side of the rhizome, pushes through the soil, and emerges as a sucker. Each sucker can develop into a plant, which will fruit only once, and then dies.

Pruning

Pruning is the process of cutting suckers, or followers, at ground level, where they emerge from the mother plant. The main reason for pruning is to arrange for the uniform harvest of a plantation throughout the year. As indicated before, when a field is planted to bananas, the plantilla crop (from new transplants) yields all at the same time. This fruit must be sold or discarded, according to market fluctuations. If one follower (sucker) was allowed to grow on each pantilla mat, then about three months later there would again be another crop ready for the first ratoon, or sucker harvest. This would result in flooding the market at one time and not having a crop ready for shipment when market demands are high. To prevent this, a pruning method was developed that is based on uniform productivity per area per year. After the plantilla crop, the suckers which have appeared on the mother plant are pruned from all but the number of plants which are slated for harvest. In this way, there is a constant year-round pruning and harvesting. For example, consider a hectare of land with 1,000 banana mats, if the variety planted produces 1.5 bunches per mat per year, the total yield would be 1,500 bunches per year. If it is decided that the harvesting interval should be every 10 days, there would be 36 harvests, or cuttings, during the year. At each of these 36 harvests, approximately 42 bunches would be cut, and the farmer would not have an over-supply at any time during the year.

Another reason for pruning is to prevent "walking" of the mats (spreading of the mat wider and wider) and the formation of holes and crowded areas in the field. Furthermore, young suckers take away nutrients from the mother plant which is setting fruit. In the above example, the pruner allows 40 to 42 suckers of the same age to develop in scattered locations in the hectare. Pruning is done usually at 10 to 14 day intervals. A practiced pruner maintains the mat within a one-meter square of its original planting and retains uniform shading and cultivation in the field.

Prevention of Doubling or Falling Over

There are two main reasons for the falling over of banana plants during low velocity winds. These are: (1) high water table, and (2) root and rhizome injury. In poorly drained soils, rhizomes grow out of the soil and only lateral shallow roots support the plant. At times, even without the slight pressure of a low velocity wind, the plant falls over. Nematodes, such as *Radopholus similis* and *Pratylenchus coffeae*, at times completely destroy the root system. The rhizome keeps growing out of the soil and sending roots down into the soil. A light wind usually topples these nematode-infested plants. The banana root borer (*Cosmopolites sordidus*) can tunnel through the rhizome. When large numbers of these borers infest a plantation, their damage to the rhizomes causes toppling of the plants.

The doubling of the stems occurs during moderate winds of 15 to 30 kilometers per hour. To prevent this loss, plants are either propped or made steady with guys. In propping, two bamboo poles support the leaning stem, while in guying, the neck of one plant is tied by a rope to the base of the other. Guying is the most effective method of supporting banana plants.

Generally the shorter a variety and the thicker its trunk, the greater is its resistance to doubling by winds. Also, the cooking varieties, due to the greater tensile strength of the parental *M. balbisiana*, are more resistant to doubling than the dessert varieties.

Time to Harvest

Banana varieties vary greatly in their rate of growth. Generally, the diploid varieties grow much faster than triploid varieties. For example, within a year a mat of the Lady Finger (a diploid) variety may produce 2½ bunches compared to 1½ bunches of the triploid variety Giant Cavendish. Also, the shorter a variety, the faster is the rate of its growth. A Dwarf Cavendish produces two bunches per mat per year while a Lacatan produces only one. Also, the inbred dessert varieties originating from *M. acuminata* have a faster rate of growth than the hybrids from *M. acuminata* and *M. balbisiana*. For example, it takes a Lacatan eleven months to produce a bunch, while it may require 13 to 14 months for French Plantain. In the plantilla crop, the size of the seed-piece determines the earliness of the harvest as indicated previously.

The duration between the emergence of a bunch (shooting) and its harvest is an important factor in the marketability of the product. This duration depends on the variety and seasonal temperatures. After the bunch emerges, folds down, and all hands are exposed, it requires 60 to 70 days before the fruit is ready for harvest. For local markets, the bunch should be harvested as soon as the fruits are full or round. For more distant markets, they should be harvested earlier when more angular. The bunches are cut and sold whole, or the hands are separated, graded and packed before sale.

Bagging of Fruit

The main reason the fruit is bagged before harvest is to grow an attractive fruit. Bagging prevents peel scratches by birds and bats, sun scalding, fungal infections which result in speckles and blotches on the fruit, and infestation by insects. In the latitudes which have cool winter nights, bagging prevents chilling of the fruit.

A fruit bag consists of a polyethylene tube lined with a layer of brown heavy crepe paper. The plastic is perforated at intervals with 10 mm holes. This is done to prevent excessive "sweating" in the bag.

A bunch is bagged as soon as it bends at its neck. The upper part of the bag is tied to the neck of the bunch. The lower end of the bag is left open. Bags are removed when the bunches are harvested.

Weed Control

Weed control is necessary before a plantation is established. An old plantation usually shades out the weeds. Weed control is also required on the borders of plantations, around the irrigation canals and drainage ditches, and plantation roadways. Application of recommended herbicides is the most efficient method of controlling weeds. If the land is properly prepared before planting, if the correct spacing is adopted, and if mulching is practiced, weed control should require little effort. Cultivation, if required, should always be shallow in order to minimize damage to the roots.

Insect Control

Bananas are attacked by a wide range of insect pests which include root borers, red rust thrips, weevil, scales, bag worms, Chalcid wasps, peel-feeding caterpillars and many other insects as well as nematodes. In order to control these pests a complete program of pesticide application is needed. In large plantations, pesticides are applied by fixed-winged airplanes. Any relaxation of digilence against pests may result in a substandard product.

Disease Control

Plantains and a number of dessert varieties such as those in the Cavendish group are resistant to Fusarium wilt or Panama disease. Cultivation of these varieties reduces preoccupation with remedies for this important disease. From a worldwide point of view, Sigatoka leaf spot is the most important and the costliest disease of bananas. In the American tropics, bacterial wilt or Moko disease is one of the most important diseases, while in the Pacific region, Bunchy Top disease may cause extensive damage. A number of fruit-blemishing diseases cause reduction in fruit quality.

Profit in Banana Production

Throughout the tropical world, if growing conditions are right, bananas are a good cash crop. With the rapid rate of population growth in the tropics, there is a greater demand for local consumption of this commodity.

For example, a small farmer in Vietnam with one hectare of land near a city, can grow about 1,000 mats of bananas, which will yield approximately 800 bunches, selling for between \$5.00 to \$10.00 each, yielding a gross annual return of $5,000. Similarly, a farmer in Puerto Rico with one cuerda (approximately 1 hectare) of land may grow about 1,700 mats of plantains, and since he allows two or three plants per mat, he harvests at least 2,000 bunches and sells them at $2.50 per bunch. For an 18-month period, his earnings are $5,000. An intermediate commercial plantation may consist of 500 hectares. If planted to Valery, it may contain 1,200 mats per hectare. If each mat produces 60 kilograms of fruit per year, the total yield will be 36,000,000 kilograms of fruit per year. Assuming the bananas to be worth 10 cents per kilogram at the plantation's boxing station, the annual gross earnings would be $3,600,000.

As the above examples indicate, banana cultivation can be a remunerative agricultural business. Of course, anticipation of market demands plays an important part in the whole endeavor. In large-scale commercial plantations, not only a great deal of technical know-how and sophisticated agricultural machinery are needed, but also, packaging, shipping, ripening, and distribution have to be considered.

CHAPTER 27

TARO AND YAUTIA [1/]
(Members of Araceae Family of Plants)

A. TARO - *Colocasia esculenta* (sometimes called *C. antiquorum*.)
Other Common Names: dasheen, malanga, tania, tanier, elephant-ear, tanyah, coco-yam, talla, gabi

B. YAUTIA - *Xanthosoma sagittifolium*, *X. violascens*, *X. brasilianse*, *X. atrovirens*
Other Common Names: belembe, calalu, eddoe, habarala, malanga, tanier, tannia, coco-yam of West Africa

These two crop plants are quite distinct botanically, but they are quite similar in general appearance, and in their culture and use. Both are herbaceous perennial tuber crops with large handsome leaves (elephant eared), and are widely cultivated for food in virtually all tropical regions.

A convenient identifying characteristic is the manner in which the petiole (leaf stem) is joined to the leaf blade. In yautia, the petiole is attached to the very edge of the leaf at the junction of the two basal lobes of the leaf. In taro, the petiole is attached within the leaf outline (i.e., on the underside of the blade).

In both plants, the edible portion is the starchy tuber (a corm), but in yautia only the laterally borne corms (cormels) are edible; while in taro, both the central corm (fleshy underground stem) and the cormels are used for food. Also, the leaves and stems of some varieties of both taro and yautia are used for food. Taro leaves are sometimes used in stews. The mature central corms of taro vary in weight from about 250 to 3000 grams or more, depending on the variety. At maturity, the cormels of both yautia and taro vary from 85 to 450 grams or more. The corms of all types (both species) usually are 2 to 4 times longer than wide, and about as big as a medium sized potato. They can be cooked like the potato, boiled, baked or fried, or used in soups.

Some kinds of taro and yautia are grown for the tender leaves and shoots that are cooked and eaten like greens. Some varieties of taro do not have strongly acrid leaves

[1/] Edited by Donald L. Plucknett, Chief Soil and Water Section, Office of Agriculture, Technical Assistance Bureau, Agency for International Development, Washington, D.C. 20523 and tubers, but all others must be cooked to destroy the acridity. The acridity is due to the presence of needle-like crystals (raphides) of calcium oxalate.

Food Value

Taro and yautia are rich in carbohydrates (starch) and quite low in protein (2 to 3% of fresh weight). They are comparable to the white potato in general nutritive value. The protein is somewhat deficient in the essential amino acid lysine resembling most cereals in this respect. These corms are richer in calcium, phosphorus and iron than the potato, and about equal in vitamin content. Being low in fats and protein, these crops, while quite palatable, are primarily energy foods and must be balanced with proteins and fats to meet human dietary requirements. The edible leaves and petioles are substantially higher than the corms in protein, fats, and minerals, but less than half as rich in carbohydrates. Thus, the leaves and petioles (occasionally eaten) are more nearly balanced for human nutrition than are the corms.

Description

Taro

A member of the Araceae family of plants, taro grows to a height of 1 meter or more under favorable conditions. The stems (corms) are short and thick. Leaf blades hang nearly to the ground, petioles are long and stout. Taro has 6 to 20 or more large spherical underground corms, which are an important foodstuff. Some varieties are grown mainly for the large main corm, while in other varieties the sucker corms (cormels) are also eaten. Dasheen types have a larger number of cormels. The blanched shoots from the tubers may be utilized as a "winter" vegetable.

Yautia

Several species of a plant genus closely related to taro are termed Yautia. The lateral corms resemble those of taro. It is probable that three species are used in the same manner as food crops. They are strongly growing herbaceous plants with broad leaves, with a coarse stalk, and main corms which are usually not eaten. One species - *X. sagittifolium*, has an above ground trunk; two other species - *X. atrovirens* and *X. violaceum*, are without above ground trunks. The *X. brasiliense* species is probably identical with *X. sagittifolium*. All species bear abundant lateral corms that are edible.

Varieties

There are a very large number of varieties of both crops, and these differ widely in yielding ability, adaptation to soils and climate, plant characteristics, size of corms, palatability and starch content. Results of limited variety tests are available in Hawaii, Puerto Rico, and at research stations in the Caribbean and the Far East. In undertaking an improvement program, a collection of the superior varieties from many tropical regions should be field tested under local conditions to determine their performance and the quality of the tubers as well as cleaned up of any diseases such as viruses that may be transmitted vegetatively. This should be followed by determining responses to fertilization, and spacing of rows and plants.

Adaptation and Culture

Taro and yautia produce best at low to medium elevations in moist regions of the tropics and the frost-free subtropics. Low land bordering rivers and streams that is too moist for sweet potato and yam production is well-suited to taro and yautia, though some varieties are adapted also to drier ground. Some varieties of taro can be grown in flooded fields, like rice. Good soil drainage is necessary for yautia. In dry regions, they do well under irrigation, but are not a priority crop where water is a limiting factor. These crops tolerate a wide variety of soils, provided moisture is adequate. Corm yields have been reported that range from a low of 3 up to 30 or more metric tons per hectare; the differences being due in part to the variety and in part to the suitability of soil and culture.

For planting, the tip section of the corm plus 20 to 30 cm of the lower petioles may be used, although corms, corm pieces, cormels, or any part of the rhizome system having buds may be used. The corms or pieces of the rhizome are set at a depth of 7 to 12 cm and covered lightly with soil; the crowns are set slightly deeper than they grew previously because the corm tip forms the base of the new corm. They are usually planted in rows about 1 meter apart, and spaced 50 to 60 cm in the row, using denser plantings in more fertile, well-watered soils. From 20 to 25 thousand propagation pieces are needed to plant a hectare. The best planting time is the cool season of the year, although plantings may be made at any season if moisture is adequate.

Fertilization

Taro and yautia are most productive in well-manured or liberally fertilized soils. It is probable that nitrogen fertilizers will stimulate vegetative growth, and that potash fertilizers will be needed for good corm development. Phosphate fertilizers will foster strong root development on soils deficient in phosphorus, and these fertilizers should be placed near the propagation piece and slightly below, so that the growing root system will have early and continuing access to the nutrients.

The time required to mature a crop of corms depends on the variety. Some varieties are reported to produce a crop in three months, but many varieties require ten months or longer. Corms can be harvested individually as they mature, leaving the smaller ones to enlarge before the plant is removed, or the entire plant can be pulled by hand when the soil is moist and most of the corms have matured.

Pests and Diseases

Taro and yautia are comparatively disease and pest free. The most severe leaf disease in taro is taro blight, caused by *Phytophthora colocasiae*. If uncontrolled, this disease can defoliate the plants. There are lethal viruses of taro in the British Solomon Islands in the Pacific. White grubs and wireworms can damage corms but generally do not limit production. During very dry weather, aphids and red spider mites sometimes appear in large numbers on foliage, but do not damage the plants severely. In the Pacific Islands, taro is sometimes severely injured by the taro leafhopper. Root-knot nematode infestations will stunt the plants and reduce yields. In the field, corm rots can be caused by *Pythium* species. Storage rots can occur when corms are stored in damp places.

CHAPTER 28

CASSAVA [1]
(*Manihot esculenta*)

Other Common Names: Manioc, yuca, tapioca, mandioca, guacamote.

Geographic Distribution

It is believed to be native of tropical America, and was introduced by Portuguese explorers of the 17th century into other tropical regions of the world.

The FAO reported production in 1969 amounted to 33 million metric tons in South America, 31 million in Africa, and 21 million in Asia, and 1/2 million tons in Central America and the Caribbean. Cassava is grown in all tropical countries for its starchy roots, as a subsistence crop, for local commerce, and as an industrial crop in many countries.

Food Value and Utilization

Cassava is a starchy food, valuable as an energy source. The tubers average about 33% carbohydrate (twice as high as the potato, because of lower moisture content) but only about 1% protein and 0.3% fat. In addition to being very low in vitamins and protein, the protein is somewhat deficient in the essential amino acids, methionine and tryptophan. Cassava is relatively high in calcium, phosphorous, and iron. The young leaves of the "sweet" varieties are edible, and are a much better source of minerals and vitamins than the tubers. Also, the leaves are considerably higher in protein and lower in carbohydrate than the tubers. The leaves average from 3.7 to 10.7 percent protein on a fresh weight basis and 21 to 36 percent on a dry weight basis. Of the essential amino acids, only methionine is deficient. Lysine levels are quite good (5.6 to 8 percent).

There is continuous variation between the sweet and the bitter types. The bitter types contain a higher percentage of poisonous hydrocyanic acid in the roots than the sweet types. The sweet types are grown mainly for boiling and eating as vegetables. The cyanide is released when the tubers are grated and the juice is drained off, for making flour. The cyanide also is eliminated by thorough boiling or by roasting of the roots.

[1] Edited by Eduardo Alvarez-Luna, Director, Plant Sciences, International Center of Tropical Agriculture, Cali, Colombia

When the grated roots are washed the eluent contains starch which separates out on standing. While the starch is still moist, it is pressed through fine mesh screens onto a hot ceramic plate to form commercial tapioca; or it is dried to form the flour used in many bakery products. Tapioca and starch are exported from a number of countries on all continents, dominated by Brazil, Thailand and Indonesia.

Adaptation

Cassava is relatively drought resistant, and is a particularly useful crop in all regions with alternating dry and rainy seasons. It makes good growth when moisture supply is adequate, and becomes virtually dormant but stays alive in drier periods. Since the plant is essentially a perennial, it can be allowed to stand indefinitely as a crop, and the tubers harvested whenever needed. However, it may be grown as an annual, producing a crop of tubers within 9 to 12 months after planting when moisture is adequate for sustained growth.

Cassava requires a warm climate, but is grown extensively in subtropical regions that are frost-free, as well as in the true tropics. In tropical highlands, it is rarely grown above altitudes of 1500 meters.

Soil requirements are not very stringent, but better yields are produced on deeper soils. It does not endure imperfect soil drainage, and thus is not suited as an alternate crop on lowland rice fields. Although cassava has a reputation for adaptation to soils of widely varying soil fertility, higher yields are obtained only on more fertile soils. In contrast to customary yields of 3 to 5 metric tons per hectare on subsistence fields, yields of 30 or more tons have been produced on friable, deep, fertile soils. Fields that have been continously cropped should be fertilized for improved cassava production. The reported responses to green manure crops (*Crotalaria* species) indicates a need for nitrogen. Favorable responses to banded application of phosphate and potash fertilizers should be similar to those reported for other tuberous crops. A basic problem for subsistence farmers, is to gain access to credit or other assistance that will make it possible to implement the technology for improved production.

Description

Cassava is a shrubby perennial that grows 2 to 3 meters tall, with erect, clean stems, and palmately divided leaves on long stalks. It produces large, elongated, fleshy, tuberous roots that are rich in starch. The size of the roots depends on age and growth conditions, often reaching lengths of 40 cm and weights of 5 or more kg. The roots tend to become more fibrous after 12 to 14 months of age, and, hence, the crop is usually harvested while still fleshy. Propogation is by cuttings obtained from the stems of plants that are at least 10 months old and 2.5 to 3.5 cm thick. After stems are harvested, they are stored for a short while in a protected dry place until planting time. Cuttings of some 25 cm in length are taken from the lower part of the stem after discarding the basal 20 cm, and the upper stem having less than 2.5 cm diameter.

The cuttings produce roots from the nodes below ground level after planting, and new shoots from the uppermost buds at the stem nodes. The root system is well-branched, and occupies the soil deeply. After a few months, certain roots near the stalk base become swollen with starch deposition, and these continue to grow in periods when moisture is adequate. They continue to grow indefinitely, and may be left in the soil without deterioration until harvest becomes convenient; although they become increasingly more fibrous 12 to 14 months after original planting.

Varieties

Many varieties of cassava have been reported, such as Sao Pedro Preto with high starch content, Bogor -- a "sweet" type grown in Indonesia, Ambon believed to have a higher protein content. The variety Llanera in Colombia is reputed to be substantially higher in protein content and to be superior in yields. Other named varieties are found in all cassava growing regions. Cassava will normally produce seed on plants developed beyond the vegetative stage; and breeders of this species use sexual reproduction for the development of new strains with desired characteristics. However, the general method for propagation of established varieties is by planting stem sections that reproduce vegetatively. Vegetative reproduction is effective in multiplying somatic mutations as these are found, and this may be an important source of new types. In any event, there are numerous varieties or strains of cassava found in all regions where the crop is grown.

There is ample variability within collections of cassava strains to permit selection of strains that excel in such traits as environmental adaptation, higher starch content or higher protein content of tubers, lower content of hydrocyanic acid, as well as specific plant and root characteristics. Vegetative propagation of desirable strains makes possible the rapid multiplication of any strain for field production. The principal limitation is the avoidance of virus infected plants that show abnormal chlorophyll production by mottled or streaked leaves or deficient green color; since the virus is transmitted by vegetative reproduction. Field evaluation of all available strains of cassava and selection of those with superior traits is a rapid method of improving cassava productivity.

Culture

Fertilization

As noted earlier, cassava will produce a limited crop of tuberous roots in a period of 12 months, without fertilizers, on a wide range of soils. However, the crop does respond to fertile soils and effective use of fertilizers.

Nitrogen fertilizers should be applied periodically every 3 months during actual growth, at 20 kg of N per hectare, to produce sustained effects on cassava. Phosphate and potash fertilizers are most effectively applied in bands before planting in furrows below the intended rows of cassava. Such banding will minimize the interaction of the fertilizer with the soil mass, that is particularly likely to convert the phosphate into a form that is not accessible to the cassava. If no field trials have been made locally on amounts of fertilizers for cassava, it is suggested that initial tests be made with the equivalent of 50 kg of phosphate (P_2O_5) and 25 kg of potash (K_2O).

Seed Bed Preparation

The seed bed should be well tilled for planting the stem cuttings (about 25 cm long). These are placed in rows 1 to 1 1/4 meters apart, with cuttings about 1 meter apart in the row. The cuttings are inserted about 2/3 of their length into the seed bed so that at least the lowest node is well below the soil surface. Planting is best done at the beginning of the rainy season, and rooting and shoot development then occurs rather promptly. Any failure of cuttings can be noted in about 3 weeks, and fresh cuttings planted to replace those that failed.

Weed Control

Except for a low-growing, leguminous, green manure crop that may be grown in cassava fields, all weedy growth should be prevented. Weeds compete for moisture and soil nutrients, and thus reduce cassava yields. Pulling, hoeing or machine tillage is most effective in weed control if carried out when weeds are small, before they create serious competition. Weeding should continue until the cassava plants are large enough to shade the ground.

Disease Control

Virus and bacterial disease, largely caused by planting infected cuttings are important diseases of cassava. Also *Phyllosticta*, *Cercospora*, *Taphrina* and *Oidium* are important diseases of this crop.

Virus may be very serious but they usually spread slowly, and can largely be controlled by planting only virus-free (normal appearing) stem cuttings. All virus infected plant material with discolored or distorted leaves should be removed from fields and destroyed by burning.

Insect Pests

Cassava suffers the attack of several insects, such as thrips, hornworm, shoot fly and the spider mites. In the event of a significant infestation, prompt application of a specific purpose insecticide should be applied.

Harvest

The tuberous roots may be harvested within 9 to 12 months after planting, depending on availability of rainfall and the variety grown. In harvesting, the roots are slowly drawn from the soil by pulling on the stems, or with the help of a strong stake used like a lever tied to the stalk near its base. Since the plants remain alive, and the tuberous roots do not have a determinate maturation stage, harvest may be scheduled at a convenient time. For subsistence, the roots may be harvested intermittently over a long period, the principal limitation being that fiber content of the roots becomes increasingly higher after about 12 months from date of planting. The optimum stage of growth for harvest to produce the greatest yield must be determined by field trials in each region, for individual varieties.

CHAPTER 29

YAMS 1/
(Dioscorea spp.)

The most widely grown species of yam, in order of importance in the tropics and subtropics, and a few of their characteristics, are listed below:

1. White Guinea Yam (*Dioscorea rotundata*) - Tropical Africa, usually thorny stem, twisting right, 8 months growing season, large cylindrical tubers.

2. Greater Asian Yam (*Dioscorea alata*) - Southeast Asia, now worldwide, winged stem, twisting right, 10 months growing season, large variable tubers.

3. Yellow Guinea Yam (*Dioscorea cayenensis*) - Tropical Africa, thorny stem, twisting right, 10-11 months growing season, large variable tubers.

4. Lesser Asian Yam (*Dioscorea esculenta*) - Principally Tropical Asia, round spiny stem, twists left, 11 months growing season, small or large clustered tubers.

5. Potato Yam (*Dioscorea bulbifera*) - Throughout tropics, smooth stem, twisting left, aerial and sometimes underground tubers.

6. Cush-Cush Yam (*Dioscorea trifida*) - Caribbean region, stem winged, twisting left, 11 months growing season, small clustered tubers.

The true yams are unrelated to other crop species sometimes called yams, notably the sweet potato, and the cocoyams, which are actually taros and tanniers.

Yams provide a staple foodstuff for millions of people in many tropical and some subtropical countries, and are secondary foods for many millions more. Their large scale cultivation as food crops occurs in three main areas of the world - West Africa, South East Asia (including parts of China, Japan and Oceania), and locally in the Caribbean and in tropical Latin America.

"Edible yams are field crops, which although basically perennial, are treated as annual plants. They are harvested every season - sometimes more than once in a season, and replanted every year. They are essentially crops of the

1/ Edited by Franklin W. Martin, Location Leader, Agricultural Research Service, U.S. Department of Agriculture, Federal Experiment Station, Mayaguez, Puerto Rico 00708 humid, semihumid, or semiarid tropics, for although they are adapted to climates in which the dry or rainless season is long, they require substantial amounts of water during their growing season in order to develop their tubers. They are but little adapted to modern techniques of mechanical agriculture, and are essentially crops of peasant farmers, who cultivate entirely by manual methods. Such peasant farmers individually cultivate small acreages, and very substantial proportions of their crops are consumed by themselves, or by their families or neighbors. The yam thus belongs primarily to subsistence, rather than to commercial agriculture."*

Food Value of Yams

The nutritive value of yams as human food unquestionably varies considerably from region to region, and between species. However, an average analysis of tubers shows about 71% water, 3% protein, 23% carbohydrate (mostly starch) and 1% ash. The contents of calcium, phosphorus and iron are higher than for potato, but yams are somewhat lower in vitamin contents. Although yams are usually considered energy foods that must be supplemented with other foodstuffs to supply protein and fat needed for human diets, the protein content on a dry weight basis approaches that of cereal grains. The protein is deficient in the sulfur containing amino acids - methionine and cystine, however, as are proteins of the food grain legumes and of most plants. Some supplementation from protein rich sources is necessary to balance a yam diet.

As energy foods, yams may be used interchangeably with other root and tuber crops, and as a substitute for bananas, rice, sorghum, maize and millet. Yams are prepared for food in many ways - roasted, baked, boiled, steamed, fried, or preparations from dried flour.

Adaptation

Yams are tropical crops. They require fairly abundant supplies of water during the growing season, but may be grown over a wide range of annual rainfall zones by making growth

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*Quotation from "Yams" by D. G. Coursey. See list of "Selected References" following Chapter 40 of this Publication.
There is evidence, however, that the yam need not play only this limited role. Selected varieties grown on a plantation scale with the aid of machines and minimum vine support can yield economically attractive amounts of raw material for food, feed, or industrial purposes.

during rainy season. The choices of species and varieties must be adjusted to the probable length of seasons when rainfall is sufficiently abundant to support vegetative growth. Most varieties are adapted to rainy seasons during long days and to dry seasons during the short days of the year.

Except for D. opposita and D. japonica, the edible yams prefer temperatures above 25°C for high productivity. Excessively high temperatures may be harmful, however, especially if moisture is a limiting factor.

The tuberous characteristic of yams is an adaptation to prolonged dry seasons. When moisture becomes deficient, the plant tops die and the plant becomes dormant, but survives by means of the tubers. Thus, the yams are capable of growing in the highest rainfall areas, as well as in regions of lesser and lesser moisture supplies, down to zones with as little as 600 mm per year if rains come in a single season of 3 to 4 months. However, yams are most productive in zones having rainy seasons of 6 to 9 months duration. Yams can withstand short periods of dry weather during the growing season, because of the reserves of water in their tubers, but such shortages of moisture reduce yields.

Yams require a deep, well-drained fertile soil for satisfactory yields of tubers. The root systems are comparatively weak and cannot extract water from extensive volumes of soil, particularly in compact soils. The crop requires good soil drainage; otherwise rotting of tubers occurs.

Description

Edible yam species are herbaceous twining plants, with or without prickles, often with winged or angled stems, and large oval, parallel-nerved leaves. They produce large underground edible tubers often with hair-like or prickly rootlets. The tubers are starchy, and may vary greatly in size and shape among the various species and varieties. Under favorable conditions, the plants bloom but most species rarely produce seed. In general, the crop is propagated by planting smaller tubers or pieces of larger tubers. Plant breeders may create new varieties of some species by growing plants from seed after hybridization.

Varieties

It is possible that some of the great numbers of yam varieties were the result of somatic mutations, and that the occurrence of such mutations is continuing. Much improvement in yields and quality of tubers may be achieved by acquiring collections of varieties, and subjecting these to local field trials to determine the ones best suited to the region. When plants are virused, clonal selection is valuable for cleaning up the stock. Agricultural research stations of the region should be consulted as to the varieties that have performed well, and the source of planting materials. Improved varieties are available through the Federal Experiment Station, Mayaguez, Puerto Rico.

Culture

Fertilizers

The response to use of animal manures and commercial fertilizers varies with climate and farming system, but general responses may be summarized as follows: Animal manures and composts have produced substantially increased yields when added to the soil so that sets and tubers do not come into direct contact with these organic materials, which may cause decay. Nitrogen fertilizers are stimulating but must be applied in 2 or 3 separate applications to provide a continuing supply of nitrogen during the growing season. A single application of an equivalent amount of dung or compost will suffice for the season.

Phosphate fertilizers have produced variable results, probably because of ineffective methods of application. Phosphates must be applied in bands, nearby but below new plant sets to insure available phosphate as needed. Mixing phosphate through the soil mass of many tropical soils results in "reversion" of most of the phosphate to inert forms, unavailable to plants. Surface applications of phosphates are relatively useless because phosphates do not enter the soil with rainfall as do nitrogen fertilizers.

Potash fertilizers are useful only when accompanied by nitrogen and by phosphates applied so as to be effective.

Where reliance is placed wholly or in part on commercial fertilizers rather than copious use of manures or composts, it is suggested that applications of fertilizer to deliver the equivalent of 50 kg per hectare each of nitrogen (N) and of phosphate (P_2O_5) and 25 kg of potash (K_2O) be applied prior to planting and be supplemented by 25 kg per hectare of nitrogen (N) at intervals 3 months after planting.

Planting

The traditional method of planting yams is on raised mounds or ridges, and best results are obtained if planting holes are dug in the prepared ridge, and filled with compost or well-decayed animal manure. A 5 cm layer of soil should cover the organic fertilizer to avoid direct contact with planting sets, which may cause rotting.

Small tubers may be planted entire, but larger ones are normally cut into pieces of about 200 gm each. A general purpose fungicide may be dusted on cut surfaces of tubers to prevent rotting. Normally both small tubers and tuber pieces are planted near the time when natural sprouting occurs. Occasionally the tuber pieces are encouraged to sprout before planting them. Sprouting is facilitated by covering the cut pieces with dried grass or a moist sand and keeping them in a cool place until the shoots develop. The seed pieces are planted 50 to 100 cm apart on ridges or mounds at depths of about 5 to 10 cm. Early planting, just before or at the beginning of the rains, is most likely to produce the highest yield. Capping at the time of planting is sometimes practiced to protect the tuber from being damaged by excessive heating during dry weather. Capping consists of placing a handful of dry grass directly above the top of the tuber followed by a further covering of 5 to 10 cm of soil.

The vines of all yams are trailing, and must be supported to permit healthy development and satisfactory tuber yields. Poles or stout bamboo tops should be fixed in the ground along the rows for support of the vines, or 3 poles may be arranged around each plant in tripod fashion. Many stalking variations can be tried, but optimum height is only about 2 meters.

Weed Control

Weed control is essential for effective production of yams. Since yams germinate irregularly, weed control is most important at the beginning of the season. Later heavy vine growth tends to shade out weeds and reduce subsequent operations cost. Weeds are removed by pulling in the close proximity of individual yam plants, and hoeing between plants.

Plant Diseases

Plant diseases are usually not important problems in yam production. In the event of outbreaks of foliar spots, prompt application of a general purpose fungicide is recommended.

Insect Pests

Insect pests have been reported as being serious enemies of yams. Underground white grubs and wireworms have occasionally caused local damage. Selection of seed free from insect damage is essential. Crop rotation such that yams or other root and tuber crops are not grown on the same land in successive seasons, is a reliable preventive measure that avoids buildup in numbers of underground pests.

Harvest

The crop is ready for harvesting after the leaves begin to dry and vines die down to the ground at the end of the rainy season. The tubers may be left in the ground and used as required, provided they can be protected from vermin and other enemies. Also, they may be lifted and stored in a cool shed with good aeration. The tubers are sometimes stored under dry earth or sand to prevent loss of moisture and shriveling.

CHAPTER 30

SWEET POTATOES [1/]
(*Ipomoea batatas*)

Description

Sweet potato (*Ipomoea batatas*) is a member of the Convolvulacae family. It is perennial but is grown as an annual crop in most farming systems. Its growth is lateral, producing long trailing, rooting stems. The leaves may be ovate, heartshaped, lobed or notched according to variety. The flowers are funnel shaped and the seeds smooth coated and angular. The sweet potato blooms and sets seed abundantly in the tropics, thus permitting controlled breeding for plant improvement. The tuberous roots begin to develop within three weeks after slips are planted.

Geographic Distribution

The origin of the sweet potato is unknown, but speculation places it in the tropics of the Americas, from which it may have spread to Asia and Africa in post-Columbus times.

Since world statistics on sweet potato production are coupled with the completely unrelated yam (*Dioscorea* spp.) it is not possible with any certainty to identify the predominant sweet potato growing areas. It is clear, however, that sweet potato is a major food crop in many tropical areas of both the Old and New World. Its food potential is great as yields range from 3 to 15 metric tons per hectare.

Varieties

Plant breeders in the tropics have developed improved sweet potato varieties from true seed from crosses of a wide range of types having desired characteristics. However, many of the cultivated varieties grown in the tropics appear to have risen from somatic mutations, which are produced spontaneously from crops grown by vegetative propagation. These mutations vary widely in environmental adaptation, yield, size and flavor of the root, thus providing a range of choice for the local grower.

[1/] Edited by S.K. Hahn, Leader, Root, Tuber and Vegetable Improvement Program, International Institute of Tropical Agriculture, Ibadan, Nigeria

Adaptation

Sweet potato thrives only in warm climates and prolonged exposure to temperatures below 10°C is damaging. It has a dormant period, which may range from a few weeks to several months and does not sprout until the air temperature is 15-19°C. It is only moderately drought resistant but a good yield can be produced in from 3 to 7 months, given adequate and evenly spread rainfall (minimum 900 mm). Short periods of drought are tolerated but these have an adverse effect on yield. High humidity is undesirable as it fosters the proliferation of the leaf and stem diseases to which sweet potato is prone. Sweet potatoes tolerate wide range of soils, although a sandy loam is preferred. Heavier soils may be used but should be well tilled and ridged to provide good drainage. Planting on beds or ridges also makes harvesting much easier. Care should be taken in applying fertilizers, especially nitrogen, as this stimulates top growth at the expense of the root. However, in areas with poor soil the use of composts and manures may be advantageous. Sweet potato thrives on borders and ridges in irrigated regions, although receiving no direct irrigation. Supplementary irrigation produces good yields in areas of inadequate rainfall.

Utilization

Sweet potato tuberous roots are used for food in a variety of ways and the leaves are frequently used as a vegetable. The tuberous root requires no special processing for cooking and is both nutritious and palatable. They store reasonably well for some weeks or months after harvest if cured at temperatures of between 25-27°C for 10 days to two weeks. Large quantities are canned in industrial areas, or are sun dried or dehydrated. It is also a source of commercial starch and is used as livestock feed.

Food Value

Water	60-70%
Protein	1.6-2.0%
Carbohydrate (starch & sugar)	25-30%
Fat	0.7%
Ash	1.0%

A sweet potato which has a dry consistancy when cooked is in general, in some countries, preferred to the wet sweeter type.

The calcium, phosphorus and iron content of sweet potatoes is similar to that in white potatoes exceeding them in content of the vitamins thiamine, riboflavin, niacin and ascorbic acid. The yellow fleshed types popular in the Americas are especially rich in vitamin A.

Planting Material

The most common method of planting sweet potato is by producing rooted sprouts or "slips". To produce these, the tuberous roots should be planted horizontally and shallow in nursery beds of sand. When the sprouts produced by this method have grown about 40 cm long, they should be cut at about 30 cm to obtain slips for planting out. Slips can be obtained from the nursery bed several times at intervals of a few weeks and the process is aided by an application of nitrogen to the nursery bed.

This procedure is not used in the tropics, where 30 cm cuttings from the field crop can be planted direct, after being kept in the shade, and well watered, for two to three days. It should be noted that the terminal cutting always produces the highest yield, followed by the second cutting, and so on.

Planting

Fields are best prepared by producing ridges, 1 m apart and the slips set on these ridges at 30 cm spacing in the dry season and 40-50 cm spacing in the wet season. Slips should be cut from the nursery bed, as previously described, or from the field if the crop is being grown in the tropics.

In more temperate regions, the slips should be planted at the beginning of the rainy season, but in the tropics sweet potatoes can be grown twice a year, a crop being produced both in the moderately dry and in the wet season. For dry season growing, it should be planted at least a month before the end of rainy season to have good establishment.

In general sweet potato should not be grown on land that has produced a root crop the previous season. However, continuous cropping is possible if there is no serious disease, insect and nematode attack. The use of manures and composts is generally not required, except in areas with poor sandy, clay, or depleted soils. Commercial fertilizers may be used with advantage and should be high in potash and only moderately high in phosphate.

Fertilizer ratios should be adjusted to the soil conditions at hand, but if field trials with fertilizers have not been conducted on sweet potato it is suggested that an initial trial be made with 25 kg of nitrogen (N), 50 kg of phosphorus (P_2O_5) and 50 kg of potash per hectare. The mixed fertilizer is best placed in bands a few centimeters below the planting level. No additional fertilizer is needed as additional nitrogen stimulates aerial growth at the expense of the root, nor does broadcast phosphate and pot sium benefit the root.

Weed Control

Since sweet potato vines have a prostrate habit, regular weeding before complete ground cover is obtained is essential and it is suggested that this should be done one to three times.

Disease Control

Sweet potato is subject to a variety of virus and fungal diseases but these may be minimized by good crop management. It is important to practise crop rotation, plant only the varieties known to have resistance to locally important diseases and to remove completely all crop refuse after harvest. This refuse can be used for animal feed, or for composting, but if the disease situation is severe any residue should be burnt.

In seasons of high rainfall and humidity diseases spread rapidly, but the preventative measures cited above should afford some measure of control. If no control appears possible and the crop is badly attacked, it is suggested that no further effort be made to grow sweet potato and that some other tuberous crop, better adapted to local climatic conditions, be grown in future.

Insect Pest Control

The worst insect pest of sweet potato in the tropics is the weevil, which attacks all parts of the plant: roots, stems and leaves. The preventative measures suggested for disease control are equally effective for control of insects. If, in spite of these measures, insect attack appears to be heavy, broad spectrum insecticides approved by the government should be applied as directed. Outbreaks should be attacked promptly to avoid a build-up in the insect population. Particularly serious pests should be sent to the appropriate authority for identification with a request for a specific treatment.

Harvest and Storage

Sweet potatoes may be left in the ground for several months during the dry season but it is undesirable to do so where the soil insect population is high. If harvested during the rainy season, sweet potatoes should be stored in a well ventilated room. It should be noted that sweet potatoes in storage are readily attacked by the weevil and can cause extremely high yield losses. It is therefore essential that the crop should be chemically treated with an insecticide dust before storage. When harvesting sweet potatoes, care should be taken to avoid cuts and bruises and skinning as this will increase the danger of fungal attack. Such injuries will heal to some extent if the roots are stored in ventilated containers, at temperatures of 25-27°C for 10 to 14 days. Thereafter storage should be moderately dry to avoid spread of storage diseases.

Some varieties store much better than others, with less shrinkage and reduced losses from storage rots and weevil attack. Such varieties should be field tested locally for yield potential and resistance to disease and insect. Many superior varieties have been developed in recent years, and full use should be made of these advances.

CHAPTER 31

POTATOES [1]
(*Solanum* spp)
Common Names: papa, batata, pomme de terre

Geographic Distribution

Potatoes are grown on a worldwide basis, and rank as the fourth most important food crop in the world. The crop is thought to have originated in the Andean highlands of Bolivia and Peru. Although today potato production is greatest in the temperate zones, the potato has a definite role in food production for the tropics and subtropics, particularly at elevations above 1000 meters in the tropics, and during the cool (winter) season of the subtropics. Locally in the tropics, potatoes produce tubers in seasons with mean temperatures below 24°C. Little or no tuberization occurs above 27°C with temperate zone varieties, but varieties bred for the tropics have much wider temperature tolerances.

The tropical and subtropical countries with the greatest volume of production are:

Central America and Carribean: Costa Rica, Cuba, Dominican Republic, Guatemala, Panama
South America: Bolivia, Colombia, Peru, Venezuela
Asia: Cyprus, Korea, India, Indonesia, Pakistan, Turkey
Africa: Algeria, Ethiopia, Kenya, Morocco, Tunisia, United Arab Republic

Many other countries produce substantial amounts of potatoes in localities or regions with favorable climate conditions for seasonal production.

Food Value

The average composition of the potato tuber is 75 to 78% water, 1.8 to 2.0% protein, 17 to 20% carbohydrates (starch), 1.2% fibre, 1.0% ash, and less than 1% fat. It is low in calcium but fairly high in phosphorus. Of the vitamins, it has a substantial content of ascorbic acid. It was widely used to control scurvy by seamen in the 15th to the 19th centuries.

Nutritionally, the potato is perhaps the most balanced of the major food crops in that it provides calories and

[1] Edited by Richard L. Sawyer, Roger Rowe and Orville Page, International Potato Center, La Molina, Lima, Peru

nitrogen in proportion to adult human requirements. Potato proteins are somewhat deficient in the amino acids - methionine and cystine. However, potatoes rank next to soybeans and are superior to the cereals in total protein production per hectare.

Utilization

Potatoes have a high degree of acceptance as food in all countries where the crop is grown. They may be cooked in many ways -- boiled, steamed, baked or roasted, and fried, as well as being a satisfactory component in stews, soups, and in mixtures with meats and other vegetables. Despite their high moisture content, they store reasonably well and may be handled in commerce as a staple foodstuff.

Where production of potatoes exceeds the demand for food, they may be processed for starch, or made into alcohol, but these industries are now concentrated mostly in developed countries.

Adaptation

Potatoes of the varieties bred in Western Europe and North America, are essentially a long-day, cool-weather crop. The wide acceptance of potatoes as a food in the tropics has directed attention to varieties that tolerate a short-day tropical environment. Breeding programs appear to be developing varieties that will widen the climatic adaptation of the crop. However, the varieties now grown, many introduced from North America and Europe, are best suited to elevations above 1500 meters where temperatures permit vigorous growth. Somewhat lower elevations are acceptable in the cooler seasons of the year when mean temperatures drop to 24°C. In the subtropics, the crop is grown in the cool season, to take advantage of cooler weather. Most potato varieties will withstand light frosts.

Potatoes require a continuing supply of rainfall, preferably not less than 900 mm during the growing season for that crop. Yields of tubers are drastically reduced by prolonged dry weather.

Potatoes may be grown successfully on a wide range of soil conditions, but sticky heavy soils interfere with digging. Well drained soils are desirable. Either fertile soils or liberal fertilization is essential for abundant yields. In Europe and North America, yields of 20 tons per hectare are commonplace, whereas average yields in tropical regions are about one-half as great. Where two potato crops can be grown per year in the tropics, the total yield per hectare about equals production from one crop in the temperate zone.

Description

The potato belongs to the Solanaceae family of plants. It is an annual with stout erect stems 30 to 90 cm long. Each of the slightly hairy leaves is usually 30 cm or longer, comprised of one terminal leaflet, and two to four pairs of additional lateral leaflets. Flowers are borne in clusters of 5 to 8, with whitish or colored petals. The plant produces a fruit that may be yellowish or greenish, usually containing many seeds. Practical propagation is exclusively by tubers, borne on underground stems or stolons. The tuber is a swollen, modified stem with lateral spirally arranged "eyes"; each eye is potentially capable of producing a new plant. An eye has a number of buds, protected by scales.

The interior of the tuber is well packed with starch when fully grown, and this starch and other nutrients are moved to the eyes when sprouting and growth occurs. The size and vigor of the plant produced from cut pieces of the tuber is determined by the amount of reserve foods translocated to the eye. Seed pieces should be at least 40 grams for strong plant growth and higher yields of tubers.

The tubers are covered with a corky skin that greatly retards moisture loss. Skin color may be cream colored, brown, pink, red or purple, this being a varietal characteristic. Tuber size may vary greatly, from 30 grams to 400 grams, depending on variety and growth conditions. When a potato tuber is cut and left in a suitable environment, the cut surface forms a corky layer in a few days, which inhibits decay and excessive moisture loss. Tubers exposed to sunlight for a day or more turn greenish in color and produce a bitter substance in the surface layer that is somewhat toxic to man. Most of the toxic substance is discarded with the peelings. Potatoes for food should be protected from sun exposure, to avoid becoming bitter and toxic.

Varieties

Some varieties have been produced by selecting somatic mutations occurring spontaneously in field plantings. However, nearly all improved varieties are the result of hybridization and selection. Seedlings grown from true seed are observed for desirable characteristics when allowed to grow full size to produce commercial tuber crops. Hybridization between *Solanum tuberosum* varieties has played a major role in potato improvement. These breeding programs have largely been carried out in temperate regions, and much progress has been made in developing disease resistance, yielding ability, cooking quality, tuber storage properties and other desired traits. Many of these improved varieties have proved useful in the tropics and are widely used. However, breeding involving inter-crossing of compatible *Solanum* species and varieties has been initiated in the tropics in cooperation with potato research stations in temperate zones, and potato varieties specially adapted to a range of tropical conditions have been developed. Growers are advised to consult research stations in climates similar to their own to gain information on the most productive varieties available, as well as on improved cultural practices.

Because of the difficulty of producing seed tubers that are free of the various debilitating virus diseases in warm regions, the importation of planting seed from cooler climates or high elevations is widely practiced and highly desirable. Such seed should not only be true to variety name, but it should carry some warranty as to freedom from virus diseases. Seed growers should be counseled to produce seed tubers of the tested, superior varieties, adapted to regions of intended production.

Culture

Fertilizers

Fertilizers will almost always be required for acceptable tuber yields of potatoes. Since a crop of tubers is produced in 120 days or more in the tropics, fertilization should be adjusted to a slower growing long-season crop. Potatoes respond to animal manures and composts as well as to commercial fertilizers, when effectively used. In the event local field trials have not been made to determine the amounts and kinds of fertilizers that will produce the greatest yields, it is recommended that field trials be made with the equivalent of 500 to 800 kg/ha of fertilizer, containing about 10% nitrogen (N), 10% phosphate (P_2O_5) and 8% potash (K_2O). To be most effective, the fertilizer should be placed in bands somewhat below the seed pieces. This largely prevents inactivation of phosphates by interaction with the soil, and insures that the fertilizer will be promptly available to the young plant as well as to the growing crop.

A practical method of application is to open a furrow at the intended location of the row about 18 cm deep, then place fertilizer in the bottom, cover with 5 to 8 cm of soil, the seed pieces placed thereon, and covered with 8 to 10 cm of soil. If animal manure or compost is available in quantity, it may replace up to one-half of the fertilizer. Note that there must be a layer of soil between the seed pieces and manures to avoid seed piece rotting; and that a soil layer is required between the seed pieces and commercial fertilizer to eliminate the hazard of chemical "burning" in the event of dry weather. Growers should be advised that the broadcasting of fertilizers and manures is an inefficient method of improving soil fertility for all root and tuber crops.

Planting Material

Plantings of virus-free seed should be made with varieties proven to be well adapted to local conditions. In general, locally grown seed tubers are far less productive than certified seed since the local tubers may be heavily contaminated with viruses.

Seed tubers may be cut to sizes of 40 to 60 grams each or whole tubers of this size may be used, making certain that each piece contains at least one eye. The cut surfaces may be dusted lightly with fresh dry wood ashes, flowers of sulfur, or a general purpose fungicide to inhibit disease. Seed pieces should be allowed to stand in a shaded, ventilated place for several days before planting, to permit development of a cork layer on the cut surfaces.

Planting

The time of planting should be selected to take maximum advantage of the cool season and occurrence of rains. Potatoes may be planted in rows 40 to 60 cm apart, with seed-pieces spaced about 25 to 30 cm in the row. Planting should be at depths of 8 to 10 cm; preferable in moist soil.

Weed Control

Potatoes are not strongly competitive with weeds. Prompt removal of weeds by pulling, hoeing or tillage is essential to avoid competition with the potato plant for nutrients and moisture. Tardy weed control is serious because of the interference with tuber formation and development.

Disease Control

The most important aspect of disease control is to fully exploit preventive measures. These should include the planting of varieties known to have resistance to locally important diseases. Virus-free planting stock is highly essential, since there are no other effective treatments for these disorders. Planting is normally at a season to make the best use of cooler weather and available rainfall. Crop rotation, so that potatoes will never be planted on the same field in successive seasons, is a useful preventive measure. Planting clean seed tubers that have no seed-borne diseases, such as scab, rhizoctonia, or ring rot is imperative.

Late blight is a leaf and tuber disease that may strike during periods of high air humidity when days are warm and nights are cool. Varieties are now available that are tolerant to this disease. Spraying with appropriate fungicides is effective, if the foliage is covered by weekly applications, but this requires a degree of mechanization as well as guidance in methods of procedure that are feasible only for the more competent growers.

Pest Control

A variety of potato beetles, flea beetles, aphids and nematodes may attack potato plants. Control of these should first of all include the preventive measures listed for plant diseases, particularly crop rotation. A close watch should be maintained for any pest that may cause serious damage, and outbreaks should be met by application of a general purpose, broad spectrum pesticide, pending identification of the pest that will permit more specific control measures.

Harvest and Storage

Harvest of the mature tubers should be made on a dry day, as soon as three-quarters of the crop leaves have turned brown. Prompt harvest will reduce the possible damage by soil infesting insects that attack tubers. The tubers should be stored temporarily in a shaded, dry, well ventilated place for seven to ten days to allow time for the skin to become well suberized, and for any cuts or bruises from digging to heal. Thereafter, they may be stored most satisfactorily in a well-aerated, cool, dry place until sold or converted into food.

CHAPTER 32

ONIONS [1/]
(*Allium cepa*)

Other Common Names: cebolla, lunu, bulb onion, oignons

This field guide includes only the bulb onion, and is restricted to the types that will form bulbs in the short days of the tropics and subtropics. Onion bulb formation is promoted by long days and warm temperatures. For this reason, many varieties adapted to higher latitudes will not form bulbs under tropical conditions. Numerous so called "short day" varieties exist that can be grown successfully near the equator where daylengths are only slightly in excess of 12 hours. Apparently, the higher temperatures compensate, in part, for the short length of day.

The onion is probably native of Asia, in the Middle East region. Today, it is widely grown in Mexico, Brazil, Colombia, Ecuador, and Peru; in Iraq, Lebanon, Syria, Turkey, India, Pakistan, Thailand, and Ghana. In all of these countries, the crop is grown for dry bulbs, which are marketed as a staple foodstuff. World production totaled 10 million metric tons in 1968, of which about one-third was grown in tropical and subtropical regions.

Food Value

The edible onion bulb averages 85 to 87% moisture, 1.4% protein, 10% total carbohydrates, 0.2% fat, and about 0.6% ash. It is rich in calcium and moderately supplied with phosphate and iron. It is classed as an energy food, because the calories are supplied largely from carbohydrates (mostly sugars), but is valued most for flavoring.

Onions are edible either raw or cooked in any manner. All parts of the plant contain the pungent principle that makes onions desirable as seasoning herbs. The pungent principle is due to volatile sulfur compounds. Varieties that store the best are usually greater in pungency and stronger in flavor. Mild varieties of onions do not store as well as pungent varieties.

[1/] Edited by Edwin B. Oyer, S. Shanmugasundaram, and Robert F. Chandler, Asian Vegetable Research and Development Center, Shanhua, Taiwan, 741 Taiwan, Republic of China

Adaptation

Onions thrive best in the tropics at the higher elevations and in rather dry districts. The climatic controls of growth operate through a combination of temperature and length of day, acting on the physiological stages of development that lead to bulb development, but not requisite to flowering and seed production. Essentially, the onion is a biennial; but only the vegetative portion of the growth cycle is used to produce bulbs. Onion varieties adapted to the tropics will bulb at a 13 hour day or less, but varieties adapted to the subtropics require somewhat longer day lengths for bulbing. Onions grow well over a wide range of temperatures. However, when exposed to prolonged periods of cool temperatures (below 55°F, 13°C) some of the varieties adapted to the tropics and subtropics will produce seed stalks (bolt).

Onions are grown successfully on nearly all types of soils, but respond to mellow soil structure and relatively high fertility. The crop is sensitive to high soil acidity, probably because of toxic soluble aluminum in acid soils. It is likely that varieties differ in their tolerance of soluble aluminum, but research on this matter has not been reported. Young seedlings are susceptible to salt injury so direct seeding on saline soils should be avoided. The crop will survive periods of deficient soil moisture, but yields are sharply depressed if deficiencies are extended.

Description

The onion belongs to the Amaryllidaceae family of plants. The true stem is a short structure at the base of the plant from which hollow leaves with distinct sheath and blade portions grow. The cylinder of leaf sheaths between the bulb and hollow leaf blades is called the neck. The bulb which is the food storage organ, consists of fleshy leaf sheaths, scale leaves from which the blade portion does not elongate and the true stem. When subjected to prolonged periods of cool weather, the growing point is transformed from a vegetative to a reproductive structure which elongates. This structure, which is a hollow inflorescence axis is the scape or seedstalk. The flowering umbel is borne at its apex.

Onion bulbs vary in size, shape and color depending on the variety. It is harvested by man for food and flavoring, thus halting the normal growth cycle.

Varieties

Varieties adapted to the tropics must be resistant to local diseases, and have good size and yielding capacity, long storage properties, and the pungency or flavor desired of the onion. Some varieties found to meet most of these requirements are: Texas Early Grano, Louisiana Red Creole, L 36, Eclipse, White Creole, White Grano, Early Harvest, Texas Hybrid 28, Granex, Tropic Ace and Awakia. The Bermuda (mild) type onion will not store well for more than a few weeks, but Yellow Bermuda and Excel 986 are among the best of these.

Culture

Fertilizers

Onions are responsive to manures and commercial fertilizers. The manures should be plowed under during seed bed preparation, in the amounts available, up to 20 metric tons per hectare. Manure has growth producing properties that appear to supplement commercial fertilizers. Fertilizer applications should be at least 50 kg per hectare of nitrogen (N) and potash (K_2O), and 100 kg of phosphate (P_2O_5) drilled in bands below the intended crop row. Phosphate applied broadcast often has little value, even though needed by the crop, because many tropical soils have exceedingly high fixation properties for phosphate. Band placement avoids such loss. Band placement of nitrogen and potash is effective also, so that all fertilizer nutrients can be applied together.

Propagation

Onions may either be seeded directly in the field; or started in special seedbeds, and transplanted when seedlings are large enough to handle efficiently. Seeding directly in the field requires much more seed (4 to 5 kg per hectare in rows 40 cm apart), and there must be subsequent thinning to leave only one plant per 5 - 8 cm of row. If seedbeds are used, three kilograms of seed sown on one-tenth hectare will provide enough seedlings to plant one hectare. Despite the hand labor of transplanting this method gives greater assurance of a satisfactory crop for market purposes.

Planting

Planting, or transplanting, should be scheduled to produce strongly growing plants with leaves about 30 cm tall by the time the longest daylength is reached when possible. If the monsoon season coincides with this period, it is better to utilize the longest daylengths of the dry season to produce the crop. Rows are usually spaced about 40 cm apart, with one plant per 5 to 8 cm of row. If the requisite dates of planting or transplanting do not coincide with adequate natural rainfall, supplemental irrigation is highly desirable.

Machine planters for direct seeding and transplanting seedlings are available for commercial production of onions but these operations can be carried out successfully by careful hand labor.

Weed Control

Weed control is highly essential for successful onion production, since the tops do not shade weed seedlings and provide competition. Hand weeding should begin as soon as weeds appear, and be repeated as frequently as necessary to maintain clean fields. Chemical weed control is very effective for most types of weeds. Chloro-IPC is the most useful herbicide, and it is usually applied in three sprays; before seedlings come up (or just before transplanting), again when plants are tall enough to permit "directed" spraying without wetting the onion plants, and finally, just before the tops begin to fall over, after bulbing has reached the maximum. The difficulty with this chemical is that it leaves a toxic residue in the soil that may adversely affect growth of the next crop of another species grown on that land.

Diseases

Onions may be attacked by various diseases. Onion smut attacks very young seedlings, but does not affect healthy transplants. Pelleting the seed with tersan or arasan fungicide applied with a sticker at the rate of one kilo per kilo of seed gives good control. Downy mildew affects growing plants in cool wet weather, and rarely affects tropical onions. Pink root is caused by a soil borne organism that is most serious in hot weather at bulbing time. Some varieties are more resistant; but crop rotation so that onions are never grown on the same land more than one season in three is a useful preventive measure. Neck rot infects plants in the field but is unnoticed until rotting occurs in storage. The fungus usually attacks through bruises or wounds in the bulbs caused by rough handling during harvest. Thorough field curing after harvest, sorting out the thick necked onions that are susceptible, and clean-up to remove all diseased bulbs, are effective control measures.

Purple blotch sometimes causes appreciable loss as a bulb rot. The first symptoms of the disease are small, whitish sunken lesions with purple centers. The bulbs decay due to attack by the fungus at harvest time. No satisfactory control measure is available. The practices recommended for neck rot are advised for this disease also. The Red Creole variety is much more resistant than either Grano or Bermuda.

Insect Pests

Onion thrips are most likely to be destructive in hot dry periods. These tiny, yellowish sucking insects attack the onion leaves, giving them a blanched appearance. Rotenone dusts, or malathion sprays are effective if applied as soon as thrips are detected, and repeated at weekly intervals.

Onion maggots are the larvae of a small fly resembling a housefly, but smaller. Eggs are laid near the plant base, and the small maggot about 1 cm long, feeds on the plants and burrows into the bulbs. Dieldrin or aldrin may be applied to seed at planting, or to the soil after transplanting, as a dust or spray, to protect against this insect pest.

Harvest

Onion bulb harvest should begin after the tops have begun to break over but before the foliage has dried down completely. The onions are pulled by hand and placed in windrows so that the tops partly cover the bulbs and prevent sunscald. They are left in the windrow until tops are fully dry; the tops are then cut off, and bulbs put in crates or open mesh bags to complete curing. They may be left in the open or placed in open sheds for curing. Good ventilation through crates, bags, or bins is essential. Early in the curing process, the bulbs should be sorted to remove those with thick necks (which will not store and should be consumed promptly), damaged or decayed bulbs, and all trash and dirt.

Storage

Well cured onions will store without serious deterioration for many weeks or months; but good ventilation, low humidity, and cool temperatures will prolong the desired dormancy of the bulbs. The more pungent varieties of onions store much better than mild varieties.

Seed Production

Onion bulbs that have been stored for several weeks or months, may be set in the field when rainfall permits growth, to produce seed. The bulbs will root, produce flower stalks, and bloom and set seed rather abundantly, but only when mean daily temperatures during storage are below 15°C.

CHAPTER 33

COTTON, FOR LINT AND SEED 1/
(*Gossypium* spp)

Cotton is the most widely grown and used plant fiber in the world. It also produces seed that is used for its oil, both for food and industrial uses, and a residual product, cottonseed meal, that is high in protein.

Cotton belongs to the Mallow family of plants. The commercial varieties have been developed over a long period, by selection and crossbreeding of four distinct botanical species:

Upland cotton - *Gossypium hirsutum*
American- Egyptian cotton - *Gossypium barbadense*
Asiatic cottons - *Gossypium arboreum,* and *Gossypium herbaceum*

These species vary considerably in length of fiber and fiber strength and fineness, as well as in plant and boll characteristics. The improved varieties now widely used are those with the type and quality of fiber (lint) desired in world markets, even though much of the production is retained in some countries of origin for domestic use. Breeding cotton for higher yields and quality of fiber continues to be a major objective in many cotton growing countries, even though substantial improvements have been made in recent decades.

Cotton is usually grown as a warm-season annual, although it is possible to grow a second crop on regrowth from the stubble after the first growth is harvested. This is termed the "ratoon" crop, and is never as productive as the first growth.

The plants of commercially important varieties are perennial species grown as annuals reaching heights of 60 to 160 cm depending on variety and climate, and each plant has a main stem from which several to many branches arise. These branches may be reproductive, producing one or more flowers at successive nodes or vegetative branches which may in turn produce reproductive branches. The flowers are arranged on alternate sides of the fruiting branch, and there are three relatively large bracts (modified leaves) at the base

1/ Edited by Billy M. Waddle, Staff Scientist (Cotton), National Program Staff, Agricultural Research Service, U.S. Department of Agriculture, Beltsville, Maryland 20705 of each flower, which enclose it in the bud stage. Flower colors may range from white to yellow and change to purple a day or two after opening of the blossom.

The fruit is known as a boll, and it develops after pollination of the blossom into an obovoid, 3- to 5-celled capsule, 4 to 5 cm long. The boll splits open at maturity, exposing the seeds covered with lint hairs (fibers) that may be 1.75 to 3.75 cm long (depending on variety and species) when combed out from the seed. Depending on the variety, flowering begins 8 to 11 weeks after planting, and each individual boll will mature in 6 to 8 weeks after blooming. The storm-proof varieties used where machine stripping is available have twisted carpels (burrs) with the fibers strongly attached to the carpel walls so the seeds and lint do not fall out and are retained in the opened boll. Ripening and opening of the bolls on each plant usually occurs over an extended period. However, retention of the locks in the opened bolls makes it possible to harvest the crop in one machine stripping operation.

The individual cotton fibers are slender, single-cell hairs growing out from certain epidermal cells of the cottonseed coat. These individual fibers lengthen for about 20 to 25 days, and the cell wall thickens for a similar period, before the boll opens. Unfavorable growing conditions (limited soil moisture, inadequate fertility, leaf diseases, and insects, etc.) results in fiber of inferior quality. Normally, there are 27 to 45 lint-bearing seeds per boll. The seed coats are tough and leathery, dark brown to black, and at maturity the seed coat (hull) constitutes 25 to 30 percent of the total seed weight. The oil content of the kernels, or meats, ranges from 32 to 38 percent, being higher when there is adequate soil moisture during growth of the bolls.

Producing Areas

Cotton is grown in all warm regions of the world where there is a frost-free period of at least 180 days and mean temperatures above 25°C for 150 days. Thus, cotton production occurs in the tropical and subtropical regions and the warmer parts of the temperate zones.

Production in Europe is concentrated in Greece and Spain; in Latin America, it is in Mexico, Brazil, Colombia, Peru, Nicaragua, Guatemala, and Salvador. In Asia, the principal countries are India, USSR, Peoples Republic of China, Pakistan, Turkey, Syria and Iran; and in Africa, the major producers are United Arab Republic, Uganda, Sudan, Tanzania, Nigeria, and Mozambique. In many other countries, cotton is a major crop in the national agricultural economy, and can be grown successfully in economic competition with other regions. For world markets, the significant factor is the cost of production per kilo of lint cotton; this cost should be significantly below the current world price to provide a net return to the producer. An additional consideration is to have sufficient cotton production concentrated in each locality to justify operation of the necessary cotton gins, and special supplies for growers. Access to the results of research on cotton production technology, including improved varieties, also is important.

Yields of cotton per hectare differ widely between countries, ranging from 80 to 1150 kg of lint per hectare with a world average of 350 kg/ha in 1973. Since cost per kg of lint production declines substantially as yields per hectare increase, there are much greater net returns from higher crop yields. The effective use of modern technology to increase yields and reduce costs per kilo of crop is open to all nations, irrespective of size.

Utilization of the Crop

Cotton lint (fiber) makes up about one-third of the total weight of seed cotton, and seed makes up about two-thirds. However, the lint on each hectare has a market value about four times as great as the accompanying seed. Thus, the seed is considered a byproduct, even though it is an important component. In view of the keen competition in world markets for cotton lint, full use should be made of the cottonseed and its products to make the total cotton crop more profitable. Cottonseed protein offers one of the worlds best sources of vegetable protein for the human diet.

Over one-half of the cotton lint crop is used for clothing and household textiles. The remainder is used in industry, mostly for bags, belts, twine, and tires. The short lint is utilized in carpets, batting, wadding, and low-grade yarns, as well as for stuffing material for pads and cushions. The fuzz on the seed (linters) is used for making rayon and other cellulose products.

Cottonseed is processed to produce cottonseed oil, with hulls and fuzz (linters) as byproducts. Cottonseed is made up of hulls (30 percent), kernels or meats (seed without hulls) (60 percent), fuzz (5 percent), and waste or trash (5 percent). One metric ton of cottonseed (with hulls) yields about 200 kg of oil (with efficient extraction methods) and

800 kg of cake. When hulls are removed before extraction (which is necessary for production of meal for human food), one metric ton of naked (meats) seed should yield 330 kg of oil and 670 kg of cake. Inefficient oil extraction by hydraulic presses may produce as little as 265 kg of oil, leaving about 65 kg in the cake. Since the oil has a market value 3½ times as great per kg as the cake, failure to extract all of the oil is a loss to the producer, and a bonus to the importer of poorly processed cake.

Cottonseed Cake as a Feed

Cottonseed cake and meal constitute a high-protein feed for ruminant (cattle, sheep, goats) livestock. They are somewhat toxic for poultry and swine unless treated to eliminate the toxin-gossypol. Whole cottonseed (including hulls), when oil is extracted, averages about 28 percent protein. Extracted meats produce cake averaging about 43 percent protein.

European countries are the major world importers of cottonseed cake, where it is used for livestock feed for production of meat and milk. Since less-developed countries are seriously deficient in all proteins for human diets, it would seem logical that much of the cottonseed meal and cake should be retained for use in the producing countries. The export of high-value oil might well be expanded by efficient processing to extract all of the oil, and retaining the cottonseed cake for feeding local ruminant livestock.

Cottonseed Meal as a Food

Cottonseed and meats must be processed to eliminate the toxic ingredient gossypol. The product is a highly nutritious protein. Cottonseed meal is now used as a protein supplement in human diets, particularly where animal proteins -- meat, milk, eggs, fish -- are in short supply or too expensive for common use. Cottonseed protein is somewhat deficient in the sulfur containing amino acids methionine and cystine that are essential for human nutrition. Hence, this protein is considered an extender of animal proteins rather than a substitute. The serious widespread deficiency in protein for human diets in virtually all less-developed countries warrants the retention and processing for food of all cottonseed produced in each nation. This will require expensive investments in new seed processing machinery.

Cottonseed Oil

Cottonseed oil is classed as a semi-drying oil. It is extensively used for making margarine, as a cooking oil, and in food dressings and sauces. It is also suited for home illumination where electricity is not available. Western Europe is a major world market for cottonseed oil, and in 1969 the average market price was $268 per metric ton.

Improved Varieties

Breeding programs to develop improved varieties have been actively pursued for several decades by all of the major cotton growing countries, or by regional groups where there is cooperation between countries. The characteristics that have received the most attention are: adaptation to regional environmental conditions, yield and quality of lint, resistance to insect pests and diseases, and harvesting traits such as retention of the locks in opened bolls. Comparatively little attention has been directed to any of the seed characteristics, although efforts are being made to produce varieties that have a low content of gossypol in the seed.

In view of the values of cottonseed oil and of the cake, and the importance of cottonseed meal as a protein supplement for human diets, cotton producers should make separate evaluations of lint and seed in selecting improved varieties. This is a proper function of officials who provide guidance to cotton growers.

The concept of a one-variety community plan for each cotton growing region has become widely accepted in the last 30 years. Under this plan, a single superior variety is grown in a community so as to maintain a uniformly good quality of planting seed and fiber in the local market and to avoid mixtures with inferior kinds. When a newly proved variety has been determined to be superior, it should replace the older variety completely in one season.

Mechanical de-linting of seed is frequently done at cottonseed crushing mills, to prepare seed for planting. In one-variety communities, this facilitates distribution of approved seed and makes planting easier.

Adaptation

Mean temperatures of 25^{o}C or above during the growing season are essential for cotton to grow and mature satisfactorily, and extra-long staple (lint fiber) Egyptian varieties require substantially longer warm seasons. The shorter season varieties of upland types of cotton require 5 months for growing and maturation, and most other types, 6 months or longer. Cotton also requires fairly abundant soil moisture, particularly from blooming onward, and abundant sunshine. A fairly uniform supply of moisture (rainfall or irrigation) during the fruiting period is necessary to produce lint of good length and tensile strength; 90 cm of well-distributed water during the production season is a good average requirement for most soil types, and sandy soils require more.

Cotton is grown successfully over a wide range of soil textures, from sandy to heavy clay soils and from moderately acid to alkaline soils. Because of the heavy use of water by cotton, soils that have good moisture-holding capacity and favor deep rooting of the crop are the more productive cotton soils. A shortage of soil moisture from blooming onward often results in dropping of young bolls and stunting of the remainder, with reduction in both yields and lint quality.

Ideally, cotton prefers occasional rains to replenish soil moisture, accompanied by an abundance of sunshine. Much cotton is grown in irrigated areas, where sunshine is plentiful and water can be supplied as needed. Water requirements for cotton are heavier than for most other crops, and this water consumption is particularly high in regions of low air humidity and high temperatures.

Fertilizers

Much of the world's cotton is grown with moderate to heavy applications of fertilizer. The crop has substantial requirements for all three of the major nutrient elements - nitrogen, phosphate, and potash. All of the phosphate and potash and at least one-third of the necessary nitrogen should be provided at planting time. The remaining nitrogen may be applied 2 or 3 months later. Application of nitrogen too late in the season can result in excessive vegetative growth and delayed maturity which can create harvest problems if rainy seasons follow.

Fertilizers are most efficiently used to satisfy nutrient requirements of plants by placement in bands below the seed. Mixing complete fertilizers through the soil mass or by broadcasting on the surface, followed by tillage, nearly always results in much inactivation of the phosphate before the plant can use it. This loss is prevented by band placement. A practical method for band placement of fertilizer is to open a shallow furrow, spread the fertilizer in the furrow, cover with about 5 cm of soil, place the seed thereon, and cover with about 3 cm of soil. Such placement of fertilizer also may be made by machine planters.

It should be noted that fertilizers containing ordinary superphosphate also carry substantial amounts of calcium, magnesium, and sulfur. However, concentrated superphosphate contains little or no sulfur, and this element must be provided from other sources if it is deficient in the soil.

Field trials are needed in each major cotton growing region to determine the amounts and kinds of fertilizer to produce the most profitable crops. If such trials have not been made, it is suggested that the initial testing for fertilizer response supply about 500 kg per hectare of a fertilizer containing 5% nitrogen (N), 10% phosphate (P_2O_5) and 5% potash (K_2O) (equals 25 kg N, 50 kg P_2O_5 and 25 kg K_2O). An additional 25 kg of N should be applied as a side dressing to the growing crop when it is 2 to 3 months old.

In many strongly weathered tropical and subtropical soils, plant growth is restricted by deficiencies in one or more of the "trace" elements - manganese, iron, copper, zinc, boron, and molybdenum. Correction of these deficiencies may greatly increase response to fertilizers. Such trace elements are required in very small amounts. Until the necessary research has been done on major soil groups to determine specific deficiencies in trace elements, it may be practical to make applications of animal manures or composts which usually contain small amounts of the trace elements in available form. It is suggested that the dung or compost be spread with fertilizer in furrows, as described above. An alternate method would be to place the dung or compost in the bottom of a furrow during plowing, under the intended location of the crop row.

Seedbed Preparation

All trash or crop residues should be removed or turned under in seedbed preparation. The seedbed should be firm and mellow. Cotton is planted on ridges or beds in more humid regions, but level or furrow planting is customary in regions of moderate rainfall.

Planting

Cotton seed is planted 3 to 5 cm deep, in rows 100 cm apart, with plant spacings of no more than about 30 cm in the row. This requires about 30 kg of seed per hectare. Single plant hills are now considered to be less desirable than formerly. Delinted seed is preferred because of more rapid germination. Seed treatment to control seed and seedling diseases is usually desirable; such treatments should be locally recommended to insure protection and to comply with country regulations on use of poisonous materials.

Wherever soil erosion and rainfall runoff losses are important, on sloping lands, rows should run on the contours or across the slopes to impede runoff.

Weed Control

Cotton is very intolerant of competition with weeds for water and nutrients. Weeds should be removed while still small to provide weed control without damage to the cotton root system. Continued hoeing, pulling, or cultivation for weed control should extend until near maturity.

Disease Control

Cotton in all growing regions benefits from two disease prevention measures: (1) planting disease-resistant varieties, and (2) field sanitation. Sanitation includes crop rotation so that cotton is not planted on the same field in successive seasons; and prompt removal or turning under of all crop residues after crop harvest. These measures reduce the amount of inoculum present that would cause diseases to develop.

Insect Pest Control

Boll weevil (in North America), boll worm, and other insects that feed on leaves and bolls tend to become more serious with intensive cotton culture. Field sanitation is a prime requirement for reducing insect pests; the same measures recommended for prevention of plant diseases are useful in insect control. It is usually necessary to supplement preventive measures with applications of pesticides to combat specific insects as they appear. The treatments must be adjusted to the specific insects; and therefore, the local recommendations should be followed.

Harvest

The best quality cotton is picked promptly when ripe, to avoid straining and rotting from exposure to rain. In regions where the harvest season is dry, picking practices should be adjusted to harvest ripe bolls before they drop on the ground. Prompt picking preserves the quality of both the fiber and the seed. The most serious hazards are damage by rain, boll rots, and losses from dropping on the ground. Losses in quality reduce crop value, even if the quantity appears unaffected. The crop should be ginned as soon as feasible to preserve the lint in bales.

Cotton seed should be processed for oil extraction soon after ginning, to halt any deterioration from rotting or insect infestations. The seed saved for planting should be treated to control storage insect pests, in the same manner as other seeds or grains.

CHAPTER 34

JUTE [1/]
(Corchorus capsularis and C. olitorius)

Two botanical species of jute are grown for commercial production -- Corchorus capsularis and C. olitorius. The most easily recognizable difference between the two species is the seed pods. In C. capsularis, white jute, the pods are globular, round, and ribbed. In C. olitorius, tossa and daisee, they are slender, quill-like cylinders, ribbed, and otherwise smooth. C. olitorius tends to be finer, stronger with more luster, but differences in fiber of the two species is influenced more by the growing, retting, and stripping than by species.

These two species of Corchorus are herbaceous annuals, with stems reaching a height of 1½ to 4½ meters, 1 to 2 cm in diameter near the base, with branches only near the top when closely spaced for fiber production. The plants have alternate, oblong leaves, serrated at the edges with the two lower points prolonged into sharp teeth. The fiber is produced in the inner bark of the stems.

Production and Use

Jute is a well-known and widely used fiber, with the same common name in all West European languages. It has other common names in areas where it is grown. Production is centered largely in Bangladesh, India, and the Peoples Republic of China. Less important producers are Nepal, Burma, Brazil, Peru, and Thailand. The fiber is used mainly for bags, carpet backing, bale wrapping, twine, and ropes, but has many other uses. Total commercial production in 1971 was 2.2 million metric tons.

Jute is in direct competition with other natural fibers such as kenaf, and especially with synthetic fibers, as well as with bulk handling of commodities. In recent years, polypropylene fabric has made heavy inroads into uses of jute for carpet backing and bags.

The main features that make jute second only to cotton among natural fibers are its long, readily spun fibers, the flexibility of this soft fiber and products as compared to hard fibers, its suitability as a packaging and carpet base material, and its relatively low cost.

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Culture

Jute thrives only in fertile soil where temperatures are high and rainfall is 20 cm or more each month of the growing season. Rainfall may be supplemented with irrigation. It requires about 5 months during the long-day part of the year to produce plants satisfactory for fiber.

C. capsularis endures inundation, commonly experienced in the delta lands of the Ganges and Bramaputra rivers. This annual flooding leaves an enriching layer of sediment. However, if flooded too long, adventitious roots form on the stems, making the cleaning of the fiber more difficult. C. olitorius is grown only in higher areas not subject to flooding, and requires manure or fertilizers to provide nutrients necessary for good yields. Supplemental irrigation may also be necessary.

Fields where jute is to be grown should be well tilled before planting, which usually occurs from March to June in Bangladesh and India. Seed is usually broadcast by hand at rates of about 13 kg/ha for the larger seeded white jute and about 9 kg/ha for tossa. Lower rates can be used if planted in rows. Seeds are small and should be covered no more than 1 cm. The seedlings are thinned and the fields are weeded after the plants become well established and preferably before they reach a height of 30 cm. Equidistant spacing of about one plant per 250 square centiments, or 35 plants per square meter is recommended under ideal growing conditions. On less productive lands, a somewhat thinner stand may be left. By planting in rows with a hand-pushed drill and weeding with a hand-pushed wheelhoe, seed rates can be halved and labor costs for sowing and weeding, which require some 42% of all labor from plowing to drying the fiber, can be reduced up to 60%.

Harvesting

As the first flowers begin to fade, the plants should be cut near the ground, tied in bundles (then or later) and left in the field for 2 or 3 days until the leaves can be shaken off to supply organic matter for subsequent crops. If the plants are allowed to grow after the flowers fade, the fiber deteriorates.

Seed is produced in a part of the field left unharvested for fiber or on a separate planting. Fiber is seldom saved from plants that have been used for seed production. The area to be saved for seed should be about 1/20 the area to be planted for fiber and seed the following year.

Processing for Fiber

The stalks of jute are retted in a stream or pool of water, in preparation for separating the marketable fiber from other stem parts. In Bangladesh and India, the retting water temperature in August and September is ideal for rapid bacterial action on the submerged stalks. Under such favorable conditions, the retting takes 10 to 15 days, but longer if stems are fine and the water cool. After retting, the stalks are moved to shallow water for stripping fiber from the woody part of the stem. This is usually done by hand, a few stems at a time and the fiber washed in the stream or pool where it is retted. It is then hung on poles for air drying.

The yield of processed and dried fibers may range from 1.0 to 1.8 metric tons per hectare, depending on growing conditions; the dry fiber is about 5% by weight of the freshly harvested stalks. Percentage varies, depending on maturity (moisture content) and variety.

In Bangladesh and India, the fiber is first sorted into three or four grades from each locality, loosely baled (kutcha bales), and moved either to local mills or to baling centers for preparing for export. Here, a few inches of the coarse butt ends are cut off, the fiber is carefully sorted, and baled into high-density (pucca) bales for export.

Commercial jute fiber contains about 60 to 65% cellulose (lower than flax, ramie or cotton), and a considerable amount of lignin (woody substance), which makes such jute fiber less durable. Despite this, jute is still used in greater quantity than any other natural fiber except cotton.

Diseases

Jute is subject to severe attacks by a number of root and stem pathogens, principally fungi. Root-knot nematodes are also a serious problem in some areas. The principal control methods available are preventive in nature. Crop rotations in which jute alternates on the land with other crops not subject to the same disease are very effective where feasible. The use of disease-resistant varieties also is a very important control measure.

Field sanitation also is important in reduction of inoculum for new disease attacks. All crop residues should either be turned under or composted soon after harvest, particularly where disease has been present. Where land is used to produce a subsequent crop in the same year, the crop chosen should of course be one that is not susceptible to jute diseases.

Insect Pests

Jute is susceptible to a number of insect pests. The most damaging in major jute growing areas are the jute semi-looper (*Anomis abalifera*) and yellow mite (*Hemitarsonemus latus*). In other areas, those that attack kenaf may also be a problem. These include a striped, long-horned beetle that may spread from certain weeds to the jute crop, several species of cutworms and army worms that feed on leaves, and aphids (sucking insects).

The preventive measures for disease control will also be effective in reducing the numbers of the pests that attack jute. For outbreaks of these pests (except cutworms) application of a general-purpose, broad spectrum insecticide dust such as malathion is effective. Where large areas of the crop are affected, growers may profitably consider group action for aerial dusting, which is much less expensive on a per-hectare basis than ground level, hand or machine application.

For cutworms and other soil-inhabiting pests, a persistent pesticide such as toxaphene may be applied at planting time at the rate of 1 to 1.5 kg per hectare of technical grade material.

Chronically destructive pests should be positively identified as to species, and treatments applied that are designed to combat that particular pest. Returns from a jute fiber crop may not be adequate to support an extensive insecticide program. However, in some areas it may be found that seed can be produced only with such dusting or spraying.

CHAPTER 35

KENAF [1/]
(Hibiscus cannabinus and H. sabdariffa)

Kenaf (pronounced ken af) originally referred to Hibiscus cannabinus only, but in recent years has also included H. sabdariffa (fiber types frequently called H. sabdariffa var. altissima). These species are also known as mesta, Bimlipatam jute or Bimli, roselle (especially for the shorter branched types with edible calyx), Siamese or Thai jute, Java jute, teal, gambo, stokroos, pápoula-de-sao-francisco, and by many other local names.

The plants are single stemmed, one to four meters high when mature, with slender stems (8 to 25 mm at the base) that seldom branch when closely planted for fiber production. Different varieties range in stem color from green to red and purple. Both species have yellow or cream-colored flowers with scarlet or reddish-purple throats. Types with considerably different flower colors have been found in both species.

H. cannabinus leaves may be either simple or palmate and are borne alternately on the stem. Basal leaves are always simple. The seed capsules are cylindrical and pubescent, bearing 18 to 20 seeds per capsule. The seeds are grey in color and kidney shaped, and range 35 to 40 seeds per gram.

H. sabdariffa has slightly more yellowish-colored flowers than H. cannabinus and the flowers are smaller. The leaves of all types are palmate and deeply lobed (except basal leaves which are simple) and borne alternately on the stem. The seeds are dark brown in color and average about 60 per gram.

Uses

As a textile fiber, kenaf is frequently used with or in place of jute in the manufacture of bag fabric, twine, and carpet yarn; in countries where the cost of labor is low, kenaf has other domestic and handicraft uses. Spinners claim it cannot be spun to as fine numbers as jute; and even though it often has a better appearance, it brings a slightly lower price in the market.

As a pulp fiber, kenaf has recently gained widespread attention. Its annual production per acre is higher than

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wood pulp, but problems, especially root knot nematodes, have delayed widespread acceptance. Products produced from kenaf, ranging from writing paper to cardboard, meet established quality standards.

Production

Kenaf is grown extensively in India, Thailand and the Peoples Republic of China, and to a lesser extent in the USSR, Brazil, Bangladesh and Egypt. In addition, there is small production in each of several other countries of the Far East, South Asia, Africa, and Latin America. The Food and Agriculture Organization of the U. N. reports some 1.1 million metric tons of kenaf and allied fibers produced in 1971-72 versus 2.2 million metric tons of jute. Thailand and Bangladesh export raw fiber; most of the other kenaf is manufactured in the country where produced.

Adaptation

Kenaf is best suited to tropical and subtropical climates. It does not do well where night temperatures are below 18°C. *H. sabdariffa* requires a more tropical climate and is more drought resistant than *H. cannabinus*. Both have a much wider adaptation to soil and climatic conditions than jute. However, areas to be considered for kenaf should have rainfall of at least 100 mm per month during the growing period, with warm, uniform temperatures. Kenaf can be grown successfully under irrigation; water requirements for kenaf and cotton are similar.

Although kenaf has much less rigid soil and climatic requirements than jute, it responds actively to favorable conditions such as good soil, warm climate, plentiful water, and fertilizers. The amount of fertilizer should be adjusted to compensate for lack of fertility in the soil and should preferably be placed in bands below the depth of the seed in the row. If fertilizer requirements have not been established for kenaf, quantities and proportions of N, P, and K used for other crops can be adapted. Since growing the crop is not the most expensive part of producing the fiber, returns per unit of cost should be carefully worked out before general recommendations are made for high rates of application. However, it should be kept in mind that 50 metric tons per hectare crop of green plants removes the following nutrients: N - 175 kg, P_2O_5 - 30 kg, K_2O - 85 kg.

Varieties

Some of the better known varieties of *H. cannabinus* that require 100 to 125 days from planting to flowering during long days are Everglades 41 and 71, Cuba 108, and others developed where kenaf is being produced. Varieties maturing some 20 to 30 days later include Cuba 2032 and several Guatemala selections. Most of the better known normal (100-125 days) maturity varieties are highly photoperiod sensitive, and will grow to usable heights only during long days in areas more than about 10 degrees from the Equator. Some of the later maturity varieties are less photoperiod sensitive, and are especially useful in greatly extending the growing and harvesting season and in enabling production in areas where rainfall occurs only during short days. *H. sabdariffa* generally matures later than most of the *H. cannabinus* varieties.

Diseases

The most serious diseases attacking kenaf are largely fungal in nature, most of which are seed borne or soil borne. Control measures for the most part may consist of initial selection of disease-resistant varieties, seed treatment with organic or mercurial fungicides, and early harvest of affected areas.

The most serious disease of *H. cannabinus* is caused by *Colletotrichum hibisci*. The disease is frequently called anthracnose or tip blight. Fortunately most of the varieties in use today were selected for resistance to the then-existing strains of *C. hibisci*. However, a new and virulent strain of the organism was recently reported in Kenya where some of the normally resistant strains were attacked. *H. sabdariffa* varieties are generally less susceptible to *C. hibisci* than *H. cannabinus*.

Nematodes

The most serious pest of *H. cannabinus* is the root knot nematode *Meloidogyne incognita acrita*. There are no varieties resistant to these nematodes and the damage to the crop can be serious. Planting on new land or on land that has had a crop not attacked by root knot nematodes appears to be the best method of control. Attacks on *H. sabdariffa* are much less serious and many varieties, especially those from Indonesia, are highly resistant.

Insects

Kenaf has several major insect pests. Among them is the small, black flea beetle of the family Crysomelidea found in Southeast Asia, New Guinea, and Africa. It attacks leaves and stems of mature kenaf, and is controlled by DDT which also controls a secondary pest -- the leaf hopper of the family Cicadellidae.

The European corn borer, Pyransta nubilalis, has heavily damaged kenaf plantings in Taiwan. Control has been effected by planting corn around the kenaf as a trap crop.

The cotton stainer larva, Dysdercus suturellus, often attacks the immature seed capsules of kenaf after the adult lays eggs on the capsule. The adult may be controlled with weekly sprayings of dieldrin, equivalent to 0.5 kg of 100% active ingredient per hectare as required.

In Iran, the major pest attacking seed capsules is the larva of the spiny bollworm, Earias insulana, which may be controlled by spraying two or three times at weekly intervals with sevin at the rate of 2 kg per ha.

Aphis gossypii, the cotton aphid, sometimes attacks young kenaf and may be controlled by spraying with malathion at the rate of 2 kg per hectare.

Kenaf for fiber will not support an extensive spray program for either diseases or pests. But spraying is more likely to be advisable for a seed crop which is usually on a much smaller acreage than a crop for fiber.

Culture

A well-prepared seedbed for kenaf as with other crops is desirable. Kenaf can be broadcast or planted in drill rows. Seeding rates vary from 10 to 18 kg per hectare for H. sabdariffa and from 15 to 25 kg for H. cannabinus. The lower rates are recommended for less fertile soils and for plantings for row harvesters. Recommendations for row spacings vary from 20 cm to 45 cm for production of spinnable fiber. Row spacings as wide as 90 cm have been used for paper production trials, but firm recommendations have not yet been established.

On a moist, well-prepared seedbed, kenaf germinates quickly and will shade or crowd out most weeds. However, land that is known to be badly contaminated with weeds should not be planted to kenaf.

Harvesting

Harvesting should begin soon after flowering starts. Plants will continue to grow after flowering starts, but quality goes down and processing becomes more difficult. *H. sabdariffa* is frequently harvested before flowering even though lower yields are obtained. Reasons for such early harvests are to enable the planting of a succeeding crop, or to allow the crop to be retted before the water is gone. Seed and fiber are not obtained from the same plants.

Plants should be cut near the surface of the soil. In many parts of the world, they are harvested with a hand sickle or machete and tied into bundles. A mower can be used, but then the stalks must be gathered and tied by hand. Tractor-drawn binders have been developed that cut and tie the stems in one operation.

Preparation for Retting

In many parts of the world where labor costs are low, the fiber of kenaf is removed from the stems by retting and hand stripping as has been practiced with jute for more than a century. If the crop is to be retted on the stems, the bundles or the loose stems before tying are left in the field until the leaves dry so that they can be shaken off and left on the soil as a source of organic matter. Occasionally, the bark containing the fiber is stripped off into ribbons by hand and then retted either green or after it has been dried and stored. Hand stripping of unretted stems is usually done, however, only when mechanical ribboning facilities are not available or in the case of a extreme shortage of water.

Mechanized ribboning prior to retting is becoming increasingly popular, especially in countries recently starting to produce kenaf. Ribboning is done with a machine that has a rapidly revolving cylinder about 50 cm in diameter and 50 cm long with some half dozen beater blades running the length of it. As the stems are fed endways, they are held back by hand or by gripping rollers while the beaters knock out the wood and leave the ribbons. In the simpler machines, a few stems are fed in by hand about half way then withdrawn, and the other end is ribboned and removed. The ribboning operation is greatly expedited by a machine that takes a much larger bunch of stems all the way through and deposits the fiber at the other end.

Retting and Washing

The ribbons are then tied into bundles. The bundles of stems, or ribbons, are submerged in river, pool, or tank water and held under the surface for 7 to 30 days, depending on the temperature of the water, the age of the plants, and the number of retting organisms (bacteria) in the water. After the fiber is jerked off the stems by hand or a handful of retted ribbons are separated from the larger bundle, the fiber is washed by swishing it back and forth on the surface of the water; it is rung out and hung up to dry. Machines for mechanical washing operations have been developed, but most of the fiber is washed by hand.

Decortication or Defibering, Drying and Baling

A process, similar to mechanical ribboning is used for cleaning the fiber sufficiently for spinning without retting. In this operation, machines must be set with close clearances so that the scraping action is greatly increased. The resulting decorticated fiber is coarser and the losses are much greater than with retting. The process has been used commercially, but is not now being used extensively.

After the fiber is dried, it is sorted according to grades -- which differ from country to country -- and baled for shipment to factories or the export market.

Harvesting and handling methods for kenaf to be pulped have not been established. It has been successfully harvested by an ensilage harvester that cuts one row at a time, chops it into short lengths, and deposits the chopped material in a wagon following the harvester. Other methods are being considered.

Seed Production

Seed is not obtained from a plant harvested for fiber. Some farmers simply leave in the field about 5 percent of their fiber crop to be harvested later for seed. Others plant kenaf for seed production; this should be planted late in summer in order to prevent excessive stalk growth before the days are short enough to induce flowering if the crop is to be harvested by combine. A rate of about 10 to 12 kg per ha for *H. cannabinus* and 8 to 10 kg per ha for *H. sabdariffa* is recommended. If seed is scarce as when a new variety is to be increased, planting about 1 seed per square meter will provide much larger rates of increase. Under good field conditions, yields of 500 kg/ha may be expected, although under ideal conditions, higher yields have been reported.

Seed should be harvested when several of the lower seed capsules have dried out, even though the plant may still be flowering. In the usual hand-harvesting procedure, the plant is cut off just below the lowest seed-bearing capsule, tied loosely into bundles, and shocked to dry out for some two weeks before threshing. Many of the green capsules ripen during this drying period. With small production and very bad weather, the seed tops may have to be dried under cover.

Kenaf tops may be easily threshed with a combine. However, in many parts of the world they are threshed by beating the dried bundles with sticks and winnowing. In any case, the seed needs to be thoroughly dried some two weeks in the sun or by artificial heat before sacking and storing. Even when well dried before storage, germination falls rapidly in hot, humid climates.

Insects can quickly ruin kenaf seed. Therefore, seed needs to be treated by an insecticide such as malathion or DDT before it is stored in a cool, dry place free from rats or other rodents.

For further information, see Dempsey, J. M., Ref. No. 6.

CHAPTER 36

RAMIE [1]

(Boehmeria nivea)

Ramie, Boehmeria nivea, is a stingless member of the nettle family, Urticacea. Ramie fiber, also known as rhea fiber, is produced from the inner bark of the stems; crude ramie fiber (ribbons containing the fiber) has long been known as China grass and thus a well known product made from ramie is called grass linen.

Production and Use

In the Orient, ramie was a principal plant fiber before the introduction of cotton in 1300. It is still used in large quantities in China, where the growing and manufacturing are believed to be mainly a cottage industry type operation. Many efforts made during the current century to introduce ramie into tropical and subtropical regions have not been very successful. By 1969, production had reached 7,000 metric tons in Brazil, 3,000 tons in the Philippines, 3,500 tons in Japan, 1,500 tons in South Korea, and 600 tons in Taiwan.

Ramie stems are slender, 8 to 16 mm at the base; they may attain a height of 2 to 2½ meters in 45 to 60 days in ideal growing conditions. The leaves are alternate, broad-ovate, coarsely toothed, with long petioles. The leaves are green on the top side with a felty-white undersurface. The flowers are small, greenish white, in clusters, and highly cross-pollinated. The seeds are dark brown, very small, ovate and are produced in very large numbers.

Ramie fiber is the strongest of all plant fibers, has a silky luster, is a yellowish-cream color (pure white when bleached), and can rapidly take up and give off moisture. It has low elasticity and high resistance to shrinkage, abrasion, and decay. It is suitable for household and apparel fabrics and for many specialized uses. When blended with wool in amounts as small as 25 percent, stretch and shrink of wool are largely controlled and wear is greatly improved. A blend of 35 percent polyester fiber produces a fabric that is comfortable in hot weather and has excellent crease resistance. Ramie fiber has been used successfully for suits, shirts, underwear, household linens, ropes, twines, threads, sail cloth, impregnated canvas, and a considerable variety of industrial

[1] Edited by Elton G. Nelson, Consultant (Fibers), Office of Agriculture, Technical Assistance Bureau, Agency for International Development, Washington, D.C. 20523

products such as belting, upholstering wire rope centers, insulation for cables, firehose and for packing, especially the packing for propeller shaft stern bearing in ships. Currently, its more important uses are for shirts and suits (both alone and in blends) and for packing. Ramie leaves and tops are palatable to livestock and are high in protein.

Varieties

Many varieties of ramie are known to oriental growers, and a few are widely used because of the yield and quality of fiber, resistance to pests, and ease of harvest and processing; some of the better known varieties are Murakami, Miyazaki 112, Saikeiseishin, and Hakuri. Field testing of varieties is a highly desirable type of research for improving production in an established area and for new areas.

Adaptation

Although ramie is a tropical plant, it is sufficiently tolerant of cooler (not cold) weather to be adapted to the subtropics as well. Ramie production should be located in regions of fairly high rainfall, although supplemental irrigation may sometimes be very helpful, especially in extending the growing season.

Ramie prefers a deep, well-drained soil, not excessively acid and abundantly supplied with soil nutrients. Since each cutting of stems (2 to 6 per year) often amounts to 40 metric tons per hectare of green material, the drain on soil nutrients is very high. To avoid curtailment of growth, heavy fertilization is necessary. Deep alluvial soils have an advantage in high native fertility, but even these soils will be depleted by continued cropping unless adequately fertilized. Fields of ramie may remain productive for 10 years or more from the initial planting if adequately fertilized.

Culture

Ramie, a perennial, is propagated by stem cuttings, layering, division of parent root stalks or rhizome cutting 10 to 15 cm long. Rhizome cutting is the preferred method. The field to be planted should be plowed 15-20 cm deep, and an initial application of complete fertilizer (400 kg/ha of a 10-10-16 analysis) placed in a band under the intended position of the row. The phosphate component of the fertilizer is particularly important, since this nutrient is not effectively applied as a surface treatment, and the initial supply must sustain the plants over a period of years. Surface applications of fertilizers fairly high in nitrogen and potash should be made after each cutting of stems is harvested to maintain productivity.

Suckers are planted in rows 100 to 120 cm apart, with individual plants spaced 30 to 60 cm apart. Closer plantings will give a quicker stand. Tillage is required only to the extent of controlling weeds until a stand is established. The first crop of stems is produced some 9 to 10 months after planting, and successive crops are harvested in 45 to 90 days thereafter in the true tropics where rainfall is not limiting. Slower growth occurs during shorter days, even near the Equator. In the subtropics where a cool season retards growth, or in the wet-dry tropics, there may be only two or three harvests yearly. Usually, the stems from which fiber is taken are relatively herbaceous and unlignified when harvested.

Diseases

Ramie is remarkably free from disease but the white fungus disease, _Rosellina nectatries_, has occasionally caused severe damage to plantings in Japan and South Vietnam. It attacks underground and symptoms, often delayed, are plant wilt and yellow leaves. In new plantings some control has been obtained by soaking three hours in a 1:1000 solution of mercuric chloride just before planting. Leaf spots and stem lesions appear to be of minor importance, doubtless curtailed by periodic harvests that eliminate susceptible tissues. There are a number of disease organisms other than the above, but none are reported to be of epidemic proportions.

Insect Pests

The most serious and widespread pest of ramie is the leaf roller, (_Pilicorsis ramentalis_). The developing larvae, whitish-green in color, up to 10 mm in length, feed and pupate in the leaves that they have caused to roll up. Heavy infestations have caused complete defoliation and cessation of growth. Good control has been obtained by use of 12 kg per ha of 5 percent impregnated DDT dust.

Other insect pests that are present in ramie fields seldom have been reported to be sufficiently serious to invoke control campaigns. This fortunate situation may not continue where ramie is grown more extensively.

Harvesting

Most ramie is harvested by hand and much of it (in China) is still stripped by hand with blunt knives. Small, hand-fed decorticating machines are being used more extensively. They have many advantages over the large stationary raspador or primitive hand methods. The small machines are convenient, small investment is required, and they are more adaptable to small-holder operations. The large decorticator, or raspador, used for sisal and abaca is more efficient for a plantation operation, but it would need 800 to 1,200 adjacent hectares to keep the machines operating.

Yields of dry ribbons from field harvest amount to about 5 percent or less of the green stem weight, and the completely processed fiber (degummed) is about one half to two thirds of the dry ribbon weight, depending on the quality of the ribbons.

Processing

Unlike most other bast fibers, the fiber of ramie is not separated from other plant components by rettings, but by decortication, drying and degumming. Usually, the fiber strands -- called China grass -- produced by decorticating machines are dried and sorted into grades. After a preliminary softening, the fibers are degummed by cooking them in an alkaline buffered solution. This may be done in a pressure tank, or in an "open kettle" for a much longer time. The degummed fibers are washed with soft water and neutralized with weak acid. The most efficient method has been to degum (in pressure tank) the fiber cut to short (7.5 cm) lengths. In open kettle degumming the fiber is frequently handled in long hanks. It is obvious that degumming requires a factory-type operation, and that the availability of such an operation is indispensable to successful ramie culture. Decortication can be done with small machines in the field, but chemical degumming requires a centralized operation.

For additional information see Dempsey, J. M., Ref. No. 6.

CHAPTER 37

ABACA, MANILA HEMP [1/]
(*Musa textilis*)

Abaca or Manila hemp (*M. textilis*) is a large perennial herbaceous plant, resembling the banana, often reaching 6 meters at maturity. The stalk or pseudostem is actually made up of overlapping large leaf sheaths. The blades of exposed leaves are oblong and entire, tending to split transversely with age under wind stresses. Mature leaf blades are 100 to 200 cm long by 20 to 30 cm wide; the petiole is 50 to 70 cm long. The true stem, borne underground, is a rhizome with many buds (eyes) that produce tillers (shoots, suckers), appearing intermittently around the base of established plants. The inflorescence is a short drooping spike. The inedible fruit is 5 to 10 cm long, three-angled, curved, and seedy.

Production and Use

Abaca is a leading hard fiber crop used for marine cordage chiefly because it is one of the few natural fibers known which will withstand prolonged exposure to salt water. However, it has declined in world production since the mid-1950's as a result of strong competition from synthetic fibers. World production averaged 128,000 metric tons in 1951-55, but had dropped to 76,600 by 1972.

In 1972, the Philippines produced 73,000 metric tons of abaca fiber (96 percent of the world total). Ecuador is the only other country that produces more than 2,000 metric tons. Perhaps more important than volume of production is the fact that in the early 1960's, some 3 million smallholders were engaged in the crop's cultivation. It forms a leading cash crop for small diversified farms, rather than being a plantation industry. However, the crop is equally adaptable to small-farm and large-scale plantations.

The abaca fiber is produced from the pseudostem of the plant, yielding 1.5 to 4 percent dry fiber in the fresh stem. The fiber as prepared for market is composed of strands 2 meters or greater in length. It is very strong, light, and tends to be coarse and stiff; its principal use is for ropes and for pulp for mimeograph mats, air filters, tea bags, and sausage casings. Its use for pulp is increasing while its cordage uses are decreasing as a result of manmade fiber's popularity.

[1/] Edited by Elton G. Nelson, Consultant (Fibers), Office of Agriculture, Technical Assistance Bureau, Agency for International Development, Washington, D.C. 20523

Varieties

There are many varieties of abaca, but only a few are grown extensively. Three are best known - Tangongon, Bungulanon, and Maguindanao. Abaca belongs to a group of *Musa* species with 10 as the basic number of chromosomes, in contrast to 11 chromosomes for true banana. None of the 11 chromosome species approach abaca in tensile strength of fiber.

Adaptation

Abaca requires a hot, continuously moist climate. It is most successful in tropical lowlands with an annual mean temperature of about 27°C, a mean annual rainfall of at least 2,500 mm, and no dry season. The most important abaca regions of the Philippines average about 3,000 mm of rain per year. Like the banana, abaca grows best at elevations below 500 meters, but is planted at elevations up to 1,000 meters.

Abaca requires deep, heavy soil that is well drained and fertile. It grows best on soils of volcanic or alluvial origin, but does well also on loams with these characteristics. Good drainage is essential, but both the surface soil and subsoil must have structure to ensure good retention of moisture. The plants are shallow rooted, and the crop is completely dependent on the fertility of the upper 60 cm of soil. For higher production, manure and fertilizers (particularly phosphates) are incorporated in the soil before new plants are started; and periodic topdressings of manure and of nitrogen and potash fertilizers are made to compensate for the heavy drain on nutrients made by harvests of the tremendous volume of leaf stalks removed for fiber production.

Culture

New plantings of abaca are made either with suckers taken from established plants or pieces or "bits" of the rhizome on mature plants. The planting "bits" are cleaned by cutting off roots, and should be treated to kill insect pests and certain disease organisms, then immediately planted in holes previously prepared. The spacing of new plants varies with soil types and fertility, but is generally 2¼ to 4¼ meters apart in each direction. Fields require weeding or cultivation until heavy shade of the abaca leaves prevent weed growth.

The first cutting of full-grown leaf stalks may be made 1½ to 2 years after planting. At this time, the mat consists of 10 to 30 stalks in various stages of development. Abaca stalks are ready to harvest a little before the flower bud appears -- that is, with the emergence of the "flag" leaf. Later, as these leafstalks continue to grow on each plant or mat, harvest of mature stalks may be made at about 4-month intervals. On fertile, well-maintained soils, abaca fields may remain productive for 10 to 15 years. Without periodic fertilization, yields diminish rapidly.

Yields of processed fiber range from 300 to more than 1,000 kg per hectare annually. Exceptional yields of more than 3,000 kg/ha have been reported. Since the fiber saved makes up only 1.5 to 2.0 percent of the fresh weight of the harvested stalks, (with hand or spindle stripping), it is obvious that enormous quantities of green matter are removed, with the nutrients taken up from the soil.

Chapter 26, Bananas and Plantains, has additional information on culture, diseases and pests of Musa spp.

Diseases

The three most serious diseases of abaca are bunchy top, mosaic, and vascular wilt. Bunchy top is a virus spread by the banana aphid (Pentalonia nigronervosa) and by P. caladii. Mosaic disease is also a virus and is spread by four different species of aphids (Aphis gossypii, A. maidis, Rhopalosiphum nymphaceae, and R. prunifoliae). Vascular wilt disease (Fusarium cubense) is caused by the organism that caused the Panama disease of bananas, but goes only to certain banana varieties. The Tangongon variety of abaca is resistant. Other diseases occur on abaca, but generally have not caused widespread damage.

Virus diseases have been controlled by cutting and removing the infected plants as soon as symptoms occur, and by using planting material only from healthy plants.

Vascular wilt which lives indefinitely in the soil can be carried in runoff water or by soil being moved about in the field on machines or on the feet of men. It is therefore extremely difficult to control except by resistant varieties. It can be partially controlled by destroying diseased plants, if only a few are noted, and by planting only on soil where abaca or bananas have not been planted.

Pests

For soil-infesting insects, and those attacking below the soil surface, applications of toxaphene or dieldrin may give partial to satisfactory control. However, the occurrence of such insects will be reduced by making new plantings on land that has not grown abaca or banana for at least two years. If soil-infesting insects are suspected, an application of toxaphene at the rate of 1.5 kg of technical grade toxaphene per hectare, worked into the soil, is usually effective.

Processing

The small farmer usually processes the stalks into fiber by separating the outer layers of each leaf sheath into strips, called tuxies, 5 to 8 cm wide. The inner part of the leaf sheath is discarded in the field. These tuxies are pulled by hand, one end at a time, through a simplified stripper consisting of a finely serrated (or smooth) knife blade against a block of wood. A similar operation called "spindle stripping" is done by wrapping the end of the tuxie around a rapidly turning spindle to help pull it under the knife. The other end is then cleaned in a similar manner. As the tuxies are pulled through, the blade being pressed against the block by a spring pole, the nonfibrous pulp is scraped away in one pass under the blade.

The fibers are roughly sorted into four or five different color groups, from dark to light, as they are stripped. Fibers from the outside leaf sheaths are brownish in color, those near the outside are light-brownish yellow and become progressively lighter in color, finer, and weaker toward the inner part of the pseudostem. After drying in the sun, the fiber is moved to a warehouse, sorted into grades, and baled for marketing.

Some 5 grades of hand- and spindle-stripped abaca fiber are recognized in the Philippines, each with a subdivision for Davao (spindle stripped) and all other (hand stripped). In addition, four grades of deco (decorticated), plantation processed fiber are recognized.

Although most former abaca plantations are now producing other crops, they are potentially important in abaca production. On plantations, fiber is usually cleaned with machines called raspidors or decorticators. In this method of cleaning, stems are cut into sections about 180 cm long, split into four pieces or crushed, and fed sidewise into the machine. (More information on decorting machines is given in sections on Ramie and on sisal.) Most of these plantations use apron conveyor driers and brushing machines that further cleaned and softened the fiber after drying. Yields of dry fiber usually run about 4 percent of the fresh stem weight, much higher than with hand- or spindle-stripping.

The decorticators have very high capacity, but each decorticator requires some 800 to 1,200 adjacent hectares for efficient use of equipment.

For further information, see R. H. Kirby, Ref. No. 12 and B. B. Robinson, Ref. No. 20.

CHAPTER 38

SISAL, HENEQUEN AND RELATED HARD FIBERS [1/]

Sisal and Henequen

Sisal (*Agave sisalana*) and henequen (*A. fourcroydes*) are similar in general appearance and use. Sisal is a robust, almost trunkless herb which has a total height of 1 to 3 meters during the growth stages prior to ultimate blooming at 6 to 8 years of age. The leaves are borne in a broad basal rosette. Each leaf is thick, succulent and smooth, sessile, dark to bright green, 100 - 200 cm long, and 10 to 15 cm wide. The hardened leaf margins are smooth, or occasionally have minute spines, and each leaf has a terminal spike 1 to 3 cm long. When the plant blooms, the central inflorescence spike, commonly termed the "pole", elongates rapidly at the rate of 20 - 30 cm per day, reaching a height of 3 to 6 meters. The flowers are numerous, 4 to 6 cm across with a funnel-shaped corolla, but rarely produce seed. Instead, aerial buds in the inflorescence produce numerous vegetative bulbils that are complete young plants which can be removed and planted. Principal producing areas for sisal are in Brazil and Africa.

Henequen differs from sisal in that its leaves are grey green and have marginal spines. Also, henequen has slower growth than sisal and a life cycle of 15 to 20 years. Its production is essentially limited to Mexico, in the states of Yucatan and Campeche, and in Cuba and El Salvador. The fiber is similar to sisal in appearance but slightly lighter in color and somewhat weaker.

Production and Use

World production of fiber (including tow) from the two species, sisal and henequen, averaged 780,000 metric tons per year from 1966 through 1972. Major producers in 1972 were Brazil, Tanzania, Mexico, Angola, and Kenya. Other countries producing more than 10,000 tons were Malagasy Republic, Mozambique, Venezuela, Haiti, and Cuba. Mexican and Cuban production is henequen only.

The hard fiber of sisal and henequen is long, bold, creamy white, and strong. It is also coarse and thus not suited for uses where fineness and texture are important. The fiber is used extensively to make agricultural and parcelling twines and ropes in addition to sacking (for local

[1/] Edited by Elton G. Nelson, Consultant (Fibers), Office of Agriculture, Technical Assistance Bureau, Agency for International Development, Washington, D.C. 20523

use), carpets, and upholstery padding. More than half of all sisal and henequen is used for harvest twine.

The use of sisal and henequen for tying twines for lumber, newspapers, heavy spare parts for machinery, etc., is widespread, but these uses have diminished somewhat with the advent of plastic twine and other tying and bundling materials. The use of sisal fiber for upholstery padding likewise has diminished as the result of synthetic products serving the same purposes, but have held their place better than some cordage products.

Sisal and henequen fiber is composed of 78% of a complex substance termed lignocellulose (cellulose and pentosans), 8% lignin, 2% waxes, and 12% other (including 1% ash). These percentages are approximate and will vary from sample to sample.

<u>Prices</u>

Prices for sisal (and henequen which usually brings about 80% of the sisal price) have fluctuated widely during the past 25 years. During periods of scarcity, such as in 1951 during the Korean War and again in 1973, prices reached levels at which the product lost ground to synthetics. During the late 1960's and early 1970's on the other hand, prices were so low that many fields were not replanted. At those low prices, only the most efficient producer could make a profit.

The future price of the fiber will depend largely on the price and availability of polypropylene (or possibly another synthetic fiber). With such a high percentage of the fiber going into twine -- a product for which adequate strength is about the only requirement -- buyers are likely to use the twine that sells at the lowest price per unit of use.

<u>Adaptation</u>

Sisal and henequen are, of course, both hot weather crops. Sisal thrives where rainfall is only moderate or the wet-dry seasonal sequence is pronounced. The plants are drought resistant. However, well-distributed rainfall, with only moderate air humidity, and a short dry season favor continuous leaf growth that permits frequent harvests with higher quality fiber.

Henequen is even more tolerant of drought and does not do as well as sisal in high rainfall areas.

The plants thrive in shallow, rocky soils that are not acid. They are more productive on fertile soils, since the repeated removal of leaves causes a severe drain on soil nutrients, particularly those supplied by commercial fertilizers -- nitrogen, phosphate, and potash. Since a single planting should flourish for 6 to 8 years in most cases (much longer with henequen), fertility must be sustained for a like period. High soil fertility and adequate rainfall tend to reduce the percentage of fiber in the leaves, but the increase in numbers of leaves harvested per year and their size more than compensates for lower percentage of usable fiber in the leaf. The total number of leaves produced during the life of the plant is not greatly affected by fertility and rate of growth. Fertile soils, of course, produce larger leaves.

Culture

Land is generally fitted for planting by removal of all existing vegetation, and sometimes by clean fallowing for a year to kill all weeds and volunteer growth of native vegetation.

Henequen is frequently planted on rocky land where only the brush and trees are removed before planting.

Planting material is either bulbils or basal suckers. Suckers can be dug and planted directly, and bulbils must be grown in a nursery for a year or so before being set in the field. Generally, plants grown from bulbils produce more fiber than plants from suckers. The nursery soil should be fertile and well drained. Supplemental irrigation of the nursery may be required during the dry season to insure development of strong plants.

Fields for commercial plantings should be fertilized as needed to supplement native fertility under the rainfall conditions expected. Nitrogen and potash may be replenished during the lifetime growth of a crop by sidedressings at the onset of rains; but phosphates must be almost wholly provided by a single application before planting. Although the amount of planting fertilizer must be determined by field trials, it is suggested that a basic application consist of 500 kg per hectare of a 10-10-10 analysis fertilizer. This fertilizer should be banded and placed below the intended row, with 5 to 8 cm of soil between the band and the root depth of the transplants. In the absence of special machine fertilizer distribution for placement of fertilizer bands, a practical method would be to (1) open a shallow furrow

(30 cm deep), (2) place fertilizer band in the bottom, (3) cover with 5 to 8 cm of soil, (4) set plants and pull in soil from the sides of the furrow to completely cover plant roots. This will more nearly insure adequate nutrition and strong growth of the transplants. In more humid areas lime is frequently required.

Planting

A widely used planting pattern is a series of double rows 0.8 to 1 meter apart, with a 3.5 - 4 meter avenue between each pair to allow future access for harvest and hauling leaves. Plants are spaced 0.8 to 1 meter apart in the rows, depending on soil fertility and climatic conditions.

A green manure crop is sometimes grown between rows of young plantings, to be incorporated into the soil at a later date if the land is not too rocky to allow the green manure to be turned under. This is impractical also in areas where there is insufficient rainfall to meet both the needs of the young fiber crop and the green manure. However, a green manure crop may offer some desirable competition with annual weeds.

Diseases

Sisal and henequen have fewer problems with diseases than most crops do. Disease symptoms are often caused by nutrient deficiencies. In higher rainfall areas particularly, plants are subject to leaf spots. Other diseases are bole rot and zebra disease, but neither has been reported as epidemic.

Insect Pests

One of the few insect pests that attack sisal is the bole weevil, which produces two kinds of damage -- puncture feeding on soft tissues of the leaves by the adult and feeding by the larvae on the young unfurled leaves in the growing spike. The latter is more serious. Aldrin and dieldrin insecticides that are persistent in the soil have generally given adequate control, whether applied as spray or dust. However, the weevil is not widespread, and only the younger plants appear to be seriously damaged.

Harvesting

When plantings are grown on fertile soil without severe or prolonged drought, the first harvest of the basal leaves may be made about 2 or 3 years after planting sisal and four to six years after planting henequen. Less vigorous stands should be deferred for a longer period. Cutting may begin as soon as plants are large enough to save about 20 to 25 crown leaves on each plant after harvest. Cuttings may be repeated at 6, 9, or 12 months; in each case allowing about 20 to 25 leaves uncut for further plant growth. A useful guide is to save all leaves that are growing out of the top of the bole forming the crown, and harvest the leaves at an angle of about 80 degrees or more from verticle. Overcutting seriously reduces yields.

The cut leaves are tied in bundles and transported to the factory center for decortication. Decortication should be completed within 24 hours after cutting to avoid deterioration of the fiber.

Decortication, Washing, Drying

The most common method of separating the fiber from the leaf is by means of a raspador decorticator. This machine is basically comprised of a small, covered, rotary drum equipped with 8 to 12 blunt blades and an adjustable breastplate. Decortication is accomplished by a man who hand-feeds single leaves halfway into the machine between the rotating drum and breastplate while grasping one end of the leaf. The leaf is then withdrawn from the unit and reversed to clean the second half while the feeder holds the cleaned fiber portion. Such a decorticator will produce 135 to 180 kg of fiber per day when fresh leaves are provided and the waste is taken away by others. These machines normally work in the field near where the sisal is grown.

A central plant decorticator is also used extensively. Its cleaning principle is the same as described above, but it is much larger and requires large amounts of water flowing over the fiber as it is decorticated. The water lubricates the rapid decortication action and carries away the waste material from the machine. The leaves are fed in a layer that is gripped between link belts or ropes that hold them while they pass through the first unit of the decorticator. The cleaned fiber is then transferred to another belt that carries the leaves through a second unit that cleans the other end of the leaves. The capacity of one of these large decorticators is about 300 to 600 kg of dried fiber per hour.

The fiber is usually sun-dried on poles or galvanized wires. After drying, the fiber is sometimes beaten slightly (brushed) with a machine to soften, separate, and further clean the fiber strands.

Each country grades its fiber according to its own standards by length, color, and cleanliness. The fiber is then tightly baled for shipment.

An increasing portion of the fiber is being manufactured in the country where it is produced. Mexico, for example, exports essentially no spinnable fiber, but exports twine and rope.

Related Hard Fibers

Cantala (*Agave cantala*) is similar in structure to sisal, but the plants rarely produce flower stalks. They bear many basal suckers, which are the principal means of propagating the plant. Cantala is shorter lived than sisal, but this is influenced by soil fertility and climate. The crop is grown mainly in the Philippines, but also in Java, Malaysia, and India. Cantala fiber is not as strong as henequen.

Mauritius hemp (*Furcraea gigantea*) also resembles sisal, but its leaves are bluish green, narrower and considerably longer; also, they are slightly concave on the upper surface, and ending in a correaceous terminal tip only about 3 mm long. There are morphological differences in the flowers. Seed is rarely produced, and propagation is by means of bulbils that are produced in abundance. The crop is grown mainly in Costa Rica, where it is called cabuya, and in Mauritius. The fiber is weaker than henequen.

Salvador henequen (*Agave latonae*) is quite similar to henequen and some botanists say it is the same species. The leaves are bluish, glaucous with marginal prickles. It is propagated by suckers, and is grown principally in El Salvador.

For further information, see G. W. Lock, Ref. No. 14.

CHAPTER 39

PYRETHRUM [1/]

(*Chrysanthemum cinerariaefolium* and *C. coccineum*)

Geographic Distribution

The principle use of pyrethrum is as an insecticide. This use appears to have originated in the transcaucasus region of Iran, Turkey and USSR around 1800 A.D., as a flea and louse powder (Persian insect powder). The publication in 1850 of the hitherto secret nature of this insecticide resulted in worldwide interest in production of pyrethrum. Dalmatia, on the Adriatic coast of (present day) Yugoslavia, was a principal supplier up to about 1920, when Japan became the leading producer. The industry began to flourish in the highlands of Kenya about 1932; and that country became a principal supplier around 1940. Pyrethrum is currently produced at higher altitudes in tropical regions -- East Africa, Zaire, Brazil, and the tropical Andean countries, as well as in the original transcaucasus region and in Yugoslavia. Efforts made to establish centers of production in the U.S. (Colorado, California) were successful as far as production was concerned, but the harvest of flowers has not been satisfactorily mechanized. Commercial production will doubtless continue to be concentrated in regions with abundant hand labor that is required for harvest of flowers at the stage when their pyrethrin content is highest. Pyrethrum is most successful in sections that are free from frosts during the growing season, and not subjected to severe cold during the dormant period.

Uses

The active insecticidal ingredients of pyrethrum are found in greatest concentration in two species of the genus *Chrysanthemum* -- *C. cinerariaefolium* and *C. coccineum*; although present in other species. The fully opened flower heads contain the majority of the active constituents; the stems having only 1/10 as much. The developing seeds (achenes) carry about 90% of the total in the flower head. The active constituents are *pyrethrins*, made up of mixtures of four chemically identified compounds -- *pyrethrin I*, *pyrethrin II*, *cinerin I*, and *cinerin II*. The pyrethrins are highly unstable in the presence of light, moisture and air. Ground flowers or dusts decompose more rapidly than whole dried flowers. There are differences in pyrethrin content of

[1/] Edited by Quentin Jones, Staff Scientist (Plant Introduction and Narcotics), National Program Staff, Agricultural Research Service, U.S. Department of Agriculture, Beltsville, Maryland 20705 dried flowers, due to the strain or variety, to the region where grown, to the cultural practices used, and to the harvesting and drying procedures. Selected strains in Kenya are reported to yield 3% pyrethrin in dried flowers, but the average is about 1.3%. Commercial Japanese flowers average 1.0%, and Dalmatian flowers 0.7%.

Pyrethrins are extracted from the dried flowers by suitable chemical solvents, and purified to produce the concentrates used in sprays and dusts. These concentrates are combined with synergists or activators, using ratios of 5 to 20 parts of synergist to 1 part of the pyrethrin toxicant. The activators enhance the insecticidal activity by 3 to 5 times against flies, and 100 times against the louse, while retaining their harmlessness to all mammals, including man. The activators tend to stabilize the pyrethrins against the action of light and air, so that longer residual action is obtained from the insecticides.

Pyrethrum products are commonly applied as oil - or water-based sprays, or as dusts containing appropriate clay or talc carriers. Pyrethrum is used for four major purposes; (1) as household insecticides because of their rapid paralytic activity against flies, mosquitos, cockroaches, lice, bed bugs, etc., and their very low toxicity to man and other mammals, (2) as livestock or cattle sprays to protect against biting flies, (3) as sprays for mills, warehouses, grain in storage, etc., as protection against stored products insects, and (4) as dusts and sprays on vegetables and fruits. Their very low mammalian toxicity makes them useful for application to these food crops to control insects, shortly before harvest. The principal limitations in uses of pyrethrum insecticides are their relatively high cost, their rapid deterioration after application, and the difficulty of keeping the stored concentrates for more than one season.

The continued usefulness of pyrethrum in competition with the wide range of synthetic insecticides, its relatively high value as a cash crop where suitable climatic conditions prevail, and the importance of adequate hand labor for harvest and drying, give this cash crop significance in farming systems for small land holders in developing tropical and subtropical regions.

Description

Commercial pyrethrum species are perennial herbs, with erect growth, each plant producing a clump 15-30 cm in diameter, of very green pinnate foliage and sending up simple or sparingly forked stems, 30 to 60 cm tall, each stem bearing heads about 4 cm across. The ray flowers are white in C. cinerariaefolium, and white, pink or red in C. coccineum. The former is believed to be Dalmatian in origin, and the latter species is attributed to the transcaucasus region. The flower type is similar to the horticultural form termed "painted daisy" or "ox-eye daisy". The flower head is radiate, having tubular flowers on the central disc and ray flowers at the margin of the head. The flowers are predominantly cross-pollinated; each floret producing a single seed (achene), resembling a small sunflower seed. The pyrethrins are concentrated primarily in the developing achenes of the young flower heads and are reported to have the greatest content when the disc florets are one-half to three-quarters open.

Adaptation

The commercial pyrethrum species are adapted to regions of moderate rainfall. In the tropics, pyrethrum is grown most successfully at altitudes above 1000 meters. The crop tolerates dry seasons after flower harvest; but well distributed rainfall is beneficial during the three to four months preceding harvest. Even light frosts during the growing season are distinctly harmful, and temperatures below freezing during the dormant period will kill the plants.

Pyrethrum is best suited to well drained loamy soils, moderately fertile, without excessive acidity or alkalinity. Weed control is necessary for economic yields.

Culture

Pyrethrum plants are started in specially prepared beds and transplanted as 10-12 cm seedlings. Beds should be located in an area not previously cropped to pyrethrum, where water is available for hand sprinkling if necessary, and the soil thoroughly tilled and fertilized with a complete chemical fertilizer at the rate of 500 grams per square meter. To avoid the hazard of soil-borne diseases, the area selected should be one not previously cropped to any crop. Well developed, viable seed is planted at a rate to produce a rather thick stand of plants, covered lightly with soil; and the planted bed then mulched thinly with dried grass or straw. The beds should be moistened by sprinkling if rainfall is deficient, to foster prompt germination and strong seedling growth. About 300 grams of seed should plant 30 square meters of seedbed, and provide 15,000 to 30,000 plants for field planting.

Field Planting

Fields of pyrethrum do not produce blossoms the season of planting, depending on climatic conditions; but thereafter should produce annual harvests of flower heads for several years. All creeping grasses and broadleafed plants should be destroyed in preparation for planting.

A complete fertilizer should be placed in bands beneath the intended rows, deep enough so the root system of the transplants will be separated from the fertilizer by about 5 cm. A practical procedure is to open a shallow furrow, place the fertilizer in a band at the bottom, cover with 5 cm of soil, set the plants, and pull soil from the side of the furrow to cover the transplant roots. The amount and composition of the fertilizer should be adjusted to the soil fertility present. If local field tests have not been made, it is suggested that 500 kg per hectare of a fertilizer carrying about 5% nitrogen, 10% phosphate (P_2O_5) and 5% potash (K_2O) be applied prior to planting. Sidedressings of nitrogen and potash should be made after each harvest is made. The longevity of the planting may be extended by subsequent fertilization, but all of the phosphate should be applied before planting to be most effective.

Plants should be set in the field when seedlings are 10 to 12 cm tall, spaced 20 to 30 cm in the rows, with rows about 50 cm apart to facilitate weed control and blossom harvest. Wider spacing in the row may be desirable if moisture is likely to be deficient. Transplanting should be scheduled when rainfall is most likely to be abundant. Weed control is highly essential during the first season of growth.

Several diseases have been reported, which require setting of replacements annually to fill empty spaces in the field. Some breeding work has been done to develop disease resistant strains of pyrethrum, particularly in Kenya, and disease resistant strains should be used to the extent available. Disease attacks should be treated with a general purpose fungicide if they threaten to become epidemic. Identification of the causal organism is necessary to plan more specific control programs. Pyrethrum should be planted on land not recently occupied by that crop, as a means of reducing potential inoculum.

The only insect pests reported on pyrethrum are aphids and red spiders. The presence of toxin in the flowers should not be assumed to mean that insects will not feed on stems, leaves and roots. Insect injuries should be noted, and the specific insect identified so as to guide control measures.

Harvest

In regions where cool weather (winter) induces a dormant period, the seedlings are set in the field in spring or early summer, and they do not bloom until the following summer. In tropical climates where a dry season induces plant dormancy, plants set in the field during a rainy season, will bloom following the onset of the next season of rains. Annual crops of blossoms should occur thereafter for several years.

The flowers are ready for gathering when one-half to three-quarters of the florets across the disc-like head are opened; since the pyrethrin content is highest at that stage. A daily harvest per person may equal 40 kilos, equal to 10 kilos of dried flowers. Stripping "scoops" have been devised to accelerate the gathering of flowers, but any stems and trash reduce the quality of the harvest. This is not a serious loss in quality, if the pyrethrins are to be extracted by solvents. The flowers must be dried soon after picking, on trays in the sun, or on floors of large drying sheds or in artificial driers.

Yields of dried flowers at levels of 700 to 800 kg per hectare are considered satisfactory, even though in vigorously growing fields the yields may be much higher.

CHAPTER 40

TOBACCO [1/]
(Nicotiana tabacum)

Tobacco originated in the Americas, and soon spread around the world after the discovery of the New World. Nicotiana tabacum was the species cultivated by the Indians from Yucatan, Mexico and southward. Another species, Nicotiana rustica was grown by the Indians in Northern Mexico and northward. The first species, N. tabacum, was promptly introduced into Europe -- through Spain, France and Great Britain, but commercial production on a grand scale was first developed in the British colonies along the Atlantic seaboard. At present, N. rustica is grown mostly in countries where the climate is too cold for N. tabacum, but it is also grown for the production of insecticidal materials, because of its higher nicotine content.

Tobacco has been a major cash crop from the early 1600's and continues to this day, throughout the world. In tropical and subtropical countries alone, it is a major crop in six Central American countries, five South American countries, 15 Asiatic countries, and nine African countries. Although grown in large plantations in many regions for commerce and export, it is also grown very commonly on lesser areas by small farmers. It is probable that one-third of the total production in tropical regions is sold locally or consumed by the growers and does not enter in statistical reporting of tobacco production. It is feasible for small growers to grow high yields of acceptable quality tobacco, even though producing on a small scale.

Uses

The importance of tobacco in agriculture is its value as a cash crop, available to the small farmer as well as to plantations. It has a high labor requirement, which is in abundant supply in tropical rural regions; the technology is within the capacity of small growers; it can be fitted into a wide range of cropping systems and environmental conditions; there is generally a ready market for the crop; and it does not deteriorate rapidly when adequately cured and stored. Quality actually improves the first 2 to 3 years in storage and leaf will keep satisfactorily for 5 to 10 years depending upon leaf type and storage conditions.

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Although tobacco has no dietary nutritional value to the ultimate users, it has retained its popularity over two hundred and fifty years and shows no signs of being discarded. Fashions in its use have changed between snuff, pipe tobacco, cigars, chewing tobacco and cigarettes; and there are health hazards from cigarette smoking; but total consumption of tobacco by virtually every country continues without signs of reduction. The pleasures of tobacco defy measurement but they are of such a nature that tobacco often carries a priority to the user, including low income people with inadequate food, that is but little lower than food itself.

The export trade in tobacco attracts many developing nations; but production to meet domestic demands and thus save on the foreign exchange required for tobacco imports, concerns nearly all tropical and subtropical nations.

<u>Adaptation</u>

Tobacco is grown from 60° north latitude to 40° south latitude, wherever there is a frost-free period of 100 to 120 days. Optimum growing temperatures are between 20° to 30°C, but it tolerates temperatures up to 35 C. Tobacco thrives in both tropical and temperate climates. The crop is best adapted to regions of moderate rainfall, 500 to 1000 mm, well distributed through the growing season of 4 to 5 months. Lower rainfall during the season of ripening and harvest is actually beneficial, but low air humidity after harvest hampers the final stage of curing in which the harvested leaf is made pliable for handling without breakage. Tobacco is not suited for regions experiencing strong winds, since the plant leaves are easily damaged by winds.

Tobacco is rather sensitive to soil conditions. Soils should be well drained, only moderately fertile, neither strongly acid nor strongly alkaline, and capable of intensive clean culture without serious soil erosion. However, different types of tobacco make effective use of a wide range of soils. Thus, cigar tobacco is grown on rich loam soils with no adverse effects on quality; whereas flue-cured (bright) types are best grown on sandy loams; and air-cured (brown) burley tobacco grows best on silt loam soils derived from limestone. Tobacco is grown in rotations with other crops that suit the type of tobacco being grown. Collectively, all tobaccos cover a wide range of soil conditions; but for a specific tobacco type, the requirements are rather exacting to produce both high yields and quality.

Description

The tobacco plant is a herbaceous annual, with a stout erect stem, covered with short sticky hairs, reaching heights of one and one-half to two meters (including flower stalks) at maturity. Depending on the variety, each plant produces 20 to 30 leaves that are large (about 60 cm long and 25 cm wide), the lower ones half-clasping the stem. The inflorescences is terminal on the stalk, many flowered, producing seed capsules with enormous numbers of minute seeds, 6 to 10 thousand per gram. For production of tobacco leaf, the inflorescence is removed before blooming (called topping), to force deposition of plant food in the leaves. Leaves are ripe and ready for harvest when they assume a lighter shade of green and have thickened so that when a section of the leaf is folded it creases or cracks on the line of fold. Bottom leaves mature first, and the middle leaves some 10 days later. All parts of the tobacco plant contain nicotine, but concentration is highest in the upper leaves, and varies greatly with type of plant and method of curing. Nicotine content of cured leaf varies from 1½ - 2½% for flue-cured, to 3-5% for burley, to 4 or 4½% for dark air-cured and fire-cured tobacco. The initial nicotine content of the leaf varies greatly with variety, climate, season, soil, maturity of leaf and cultural practices.

Varieties

The tobacco plant is self-pollinated, and strains or varieties breed true to type except for occasional outcrossing. New strains and plant forms have been produced by plant breeders using artificial hybridization -- to improve yields, resistance to pests, modified plant characteristics, curing properties, and quality of leaf. There are many strains and varieties of every tobacco type. While there are real marketing advantages to growing a single variety or similar varieties of a given market type in each tobacco growing region, there is need also to continually field-test improved varieties produced by breeders at research stations. Those strains that are definitely proven to be superior should have the seed multiplied and made available to all growers. To maintain the purity of improved types, seed production should be closely supervised by trained personnel to maintain the characteristics of the new strain.

Culture

The general practice is to produce tobacco seedlings in specially prepared plant beds, and transplant these to the field when they reach suitable size. The seeds are exceedingly small, and special care is needed to produce strong, disease-free seedlings.

Seed Beds

Seed beds are located on soil not previously cropped to tobacco, or the surface soil is sterilized by wood fires burned over the entire bed. Also, seed beds may be sterilized with steam or methyl bromide gas under pressure at air temperatures of 10°C or above. The soil is fertilized with ½ kg of a fertilizer per square meter, analysing 12% nitrogen (N), 6% phosphate (P_2O_5), and 6% potash (K_2O), well worked into the soil. Also, rotted farm manure or compost free of weed seeds may be used exclusively with good results. About 30 grams (2 tablespoons) of seed is then mixed with sifted ashes to provide a greater volume to handle, and distributed evenly over 200 square meters. This should produce an average of 2 plants per square cm of bed. This area should provide enough seedlings to plant one hectare. The seeds are pressed into the surface soil with a plank, and covered thinly with fine dried grass or straw. The seed bed must be kept moist, by using a fine mist spray to avoid making a soil crust or to cause washing seed around. Regular watering is needed to develop strong seedlings, but over-watering may induce disease outbreaks.

Planting

Fertilizer

Fields are prepared for transplanting by tillage to produce a mellow seed bed, and placement of fertilizer below the intended row. The fertilizer type and amount must be adjusted to the kind of tobacco being grown as well as the soil being used. Flue-cured (bright) tobacco fertilizer should be low in nitrogen, but high in phosphate and potash. Excessive nitrogen fertilizer produces a strong flavor and an undesirable dark green leaf that cures with dark colors. For other types of tobacco (air-cured, fire-cured, cigar filler, and cigar wrapper) the fertilizer should be more evenly balanced as to nutrients, such as a 5% N, 10% P_2O_5 and 10% K_2O. The amount of fertilizer will vary with soil conditions and the crop rotation in which tobacco is grown, from 400 to 1000 kg per hectare. The high phosphate content is needed to stimulate root development, and high potash for leaf quality and "burning" properties. Animal manures (preferable rotted) and compost are useful as supplements to fertilizers on soils of lesser fertility. The chloride of potash should be avoided in fertilizers because of the ill effects of chlorine on burn and quality.

Both manures and fertilizer are most effectively used where applied in bands below the intended row. A practical method is to open furrows about 20 cm deep, place manure and fertilizer in the bottom, cover with about 5 to 8 cm of soil, place the transplants and pull in soil from the side of the furrow to cover the plant roots. Proper placement produces far greater benefits than broadcasting manure and fertilizer and incorporating it by tillage.

Transplanting

Seedlings are ready for transplanting from the seed bed to the field when the plants have 4 to 6 leaves, and are about 15 cm in height. They should be removed from the bed carefully to avoid injury to roots, and set promptly in the row when soil is moist. A small amount of water (200 cc) per plant at transplanting time will add greatly to survival if soil moisture is inadequate during planting. When seedlings are transplanted to the field, they are quite hardy. Tobacco is usually planted in rows 50 cm to 1 meter apart, using the wider spacing in sandier soils and regions of less dependable rainfall. Plant spacing within the row may vary from 30 to 60 cm, being adjusted to varietal size and soil fertility.

Weed Control

Weeds reduce yields greatly, damage the quality of the cured leaf, and reduce market price per kilo of cured tobacco. They may be controlled effectively by cultural practices. To be most effective in protecting the tobacco crop, weeds should be removed while still small by repeated cultivations during the growing season. Remaining weeds may be removed by hand hoeing. Soil loosened by cultivation aids water penetration and formation of a low ridge reduces chance of drowning during excessive rains. Where labor is scarce weeds may be controlled also with commercial herbicides such as enide or tillam. However, this method has just begun to be accepted in areas where tobacco culture is well established and intensive.

Diseases

Tobacco yield and quality can be affected by diseases caused by fungi, bacteria, viruses, nematodes, air pollutants, and improper nutrition. Before control measures can be recommended, the pathogen must be identified. Laboratory identification is the best method, but symtomatology is also important and in some cases can be sufficient for reasonably certain identification.

Among fungal root diseases black shank is one of the most destructive. In warm weather the fungus invades through the roots causing sudden wilting and blackening of the lower part of the stalk. If the stem is split or sliced longitudinally through the diseased shank, the pith is usually found to be brown to black and separated into discs. In contrast to black shank, black root rot is favored by cooler temperatures. Both diseases can occur in the plant bed, but are more common in the field. Black root rot is indicated by blackening of the roots in a manner such that young roots are entirely blackened and rotted through and older roots have large, rough, black lesions. Fusarium wilt is caused by a soil-borne fungus that affects the vascular or conducting elements of the stem often causing a distinctive one-sided dwarfing, yellowing, and wilting. Another soil-borne fungus causes seedling damping-off, attacking the plants near the soil line and causing a brown soft-rot that girdles the base of the stem. With this last disease the roots may remain white or decay only after considerable time.

Root knot, a warmer climate disease caused by nematodes, is characterized by swollen, spherical, or irregularly shaped galls anywhere throughout the root system that vary from about 1 mm up to a few cm in size. They can be so close together as to appear as a single, irregularly swollen, elongated gall.

Bacterial or Granville wilt is favored by warm, wet weather, first becoming noticeable with the wilting of one or a few leaves during the afternoon. The wilting worsens with time and the leaves become light green to yellow and more wilted. Eventually all the leaves die, but they usually continue to hang to the stalk. The vascular tissue and pith usually are found to be brown when the stem is cut. If a stem section containing vascular tissue is placed in water, fine milky-white strands of bacteria will be seen coming out of the diseased area.

Wildfire is a bacterial leaf disease of plant bed and field plants that is favored by wet weather and driving rains. It is characterized by pale, yellowish, circular spots 3 to 6 mm in diameter that develop a reddish-brown, dead center and a distinctive yellow halo ultimately reaching 25 mm or more in diameter.

Blue mold is the most important fungal leaf disease in cooler weather while brown spot and frogeye are more important in warmer weather. All are favored by abundant atmospheric moisture. Blue mold occurs on seedlings or field plants causing some twisting or cupping of leaves, circular yellow spots that become dead and brown on the upper surface, and the diagnostic bluish, downy mold on the lower surfaces. Infection by the brown spot fungus is actually favored by moderate temperatures. The typical brown spot lesion on field plants has a roughly circular, brown, dead center with concentric rings surrounded by a halo of yellow tissue. The lesions are usually 0.5-4 cm in diameter. The halo is not always present and is less well defined than the wildfire halo. Frogeye leaf spots are usually 2-15 mm in diameter, are usually more common in the field than in the plant bed, and can resemble brown spot lesions, but more typically have a white or gray, thin, dead central area surrounded by a darker border. Tiny black spots of fungal sporulation are often noticeable in the centers of these lesions. The frog-eye fungus also causes green spot on cured leaves. Anthracnose can occur in the field but is probably more common in plant beds during or after wet weather. The lesions are small, up to 3 mm in diameter, at first water-soaked and then drying out to a papery thin, white spot, sometimes with a darker border. Powdery mildew or white mold is favored by moderate temperatures and does not require high humidity. It is characterized by white-gray, powdery, felt-like patches that often result in brown, dead lesions.

Tobacco is susceptible to numerous virus diseases which cause leaf symptoms that usually are partially described by the names of the disease. Mosaic, the most common virus disease, causes a mottled pattern of light and dark green areas that is most conspicuous on the younger leaves. Among the more important of the other virus diseases are etch, veinbanding, leaf curl, and ringspot.

Atmospheric ozone, sulfur dioxide, and nitrogen dioxide can cause severe leaf injury on tobacco in industrial areas or where nearby gasoline-burning automobile traffic is heavy. The most common symptoms are small white flecks or spots of dead tissue. The symptoms of nutritional disorders will not be covered here as they mostly resemble those on other plants.

Tobacco diseases are controlled wholly or in part by certain cultural practices, resistant varieties, and chemical means. Production of disease-free seedlings in sterilized plant bed soils, promptly plowing down stalks and other debris after harvest, and use of rotations involving tobacco only once in 3-5 years are all very important. Wildfire in plant beds can be controlled by sprays of certain copper compounds and streptomycin. Blue mold and anthracnose in plant beds can be controlled by dusts or sprays containing zineb, maneb, or ferbam. Tobacco in rotation should follow such crops as maize, small grains, sorghum, or millet. Ground nuts should be avoided in such rotations, as should such tobacco relatives as tomatoes, potatoes, and peppers. Black root rot becomes very limited when soil pH is kept below 5.6. Certain multipurpose chemicals assist in control of the root diseases, especially when used in conjunction with resistant varieties.

Tobacco varieties have been released in recent years that are resistant to one or more of the following diseases: black shank, black root rot, *Fusarium* wilt, root knot, bacterial wilt, wildfire, blue mold, powdery mildew, and tobacco mosaic viruses. However, varieties resistant to many of these diseases are available only for certain types of tobacco.

Insects

The major tobacco insect pests vary considerably throughout the world and damage may range from slight injury to complete devastation of the crop if remedial measures are not taken. In addition, the insect complex in the seedbeds will usually vary from that found in the field. However, with poor sanitation in the seedbed some of these pests, particularly flea beetles (*Epitrix* spp.), aphids, and the potato tuber moth (*Gnorimoschema operculella*) may be transported to the field, aggravating control problems.

Among the Lepidopterans several species of *Heliothis* attack tobacco. *H. armigera* is listed for most of the tobacco-growing areas in the world; however, *H. virescens*, the tobacco budworm, is the primary species in the United States. These dull colored moths have a wingspread of 28 mm and are active primarily at night laying their eggs on the tobacco leaves. The newly hatched larvae migrate to the vegetative bud where they feed for 6 or 7 days. As the plant develops, the tiny holes made by the larvae greatly enlarge, giving the plant a ragged appearance but the apparent loss is deceptive since actual loss in weight of the cured leaf is minimal. However, in a severe infestation the bud may be destroyed making it necessary to rely on a sucker to replace the original vegetative bud. Generally, treatment is not justified unless 10% or more of the plants are infested. When the larvae are feeding in the bud they are protected from the insecticide, making control difficult. Best control is obtained by mixing the insecticide with a bait of coarsely ground cornmeal and dropping a small pinch of it onto the bud. The larvae leave the bud to feed on the bait and are killed. Budworms can be controlled with *Bacillus thuringiensis*, trichlorfon, carbaryl, endosulfan, methomyl, or monocrotophos.

For many years the tobacco hornworm, Manduca sexta, has been a major pest on tobacco in the United States because of its voracious appetite and ability to destroy entire fields of tobacco. This large moth is gray with 6 large orange spots on either side of its abdomen and has a wingspan of 10 cc. It is also nocturnal in habit and concentrates its eggs on the upper one-third of the plant. The larvae have a prominent horn projecting upward from their distal end and when full grown reach a length of 10 cm. Treatment is justified when 10% or more of the plants have worms 2.5 cm long or longer.

The same materials listed for Heliothis are effective against hornworms and should be concentrated either as a dust or spray on the upper 1/3 of the plant. They can also be controlled by handpicking. Another species, Manduca quinquemaculata, the tomato hornworm, is similar in appearance and habits to the tobacco hornworm but is generally more abundant in cooler climates such as in Canada. Both species are found only in North and South America.

Prodenia litura is a noctuid of the Old World, found primarily in the Middle East, India, and Australia. The moths are dull brown in color and the female lays her eggs in masses of 100 or more, covering them with scales from her body. The larvae are voracious feeders and in certain areas have shown resistance to several commonly used insecticides. However, Bacillus thuringiensis is still listed as being effective.

Various cutworms can be serious pests due to their habit of cutting the stems of young plants near the soil surface causing its death. The adults are about the size of Heliothis moths and have speckled gray wings. Trichlorfon mixed with wheat bran and scattered over the field before transplanting should give effective control.

Another Lepidopterous insect attacking tobacco in certain areas is the potato tuberworm, Gnorimoschema opercullela. The small larvae feed within the leaf, the mid-rib or in the stem. Azinphosmethul, endosulfan, or carbaryl can be used as a spray or dust.

Among the Coleopterans are several Epitrix spp. or flea beetles that may be found in North and South America. Adults are only 1.6 mm long and jump when disturbed. They rasp out tiny holes in the leaf and the larvae burrow in roots and stems of small plants. Newly set plants can be badly stunted or killed by a few insects; later in the season large numbers may build up to decrease yields. As a preventive treatment, disulfoton, a systemic insecticide, can be worked into the seedbed at transplanting time to assure availability of healthy transplants. If the preventive treatment is not used, parathion can be applied as a dust or spray. In the field, additional materials that can be used as a spray include azinphosmethyl, methomyl, and monocrotophos.

Among the Hemipterans are the green peach aphid, Myzus persicae. In Rhodesia, this aphid transmits important virus diseases known as Rosette and Bushy Top. Even where disease transmission is not involved the aphid can cause damage when heavy populations build up. Heavy feeding on the plant juices causes premature ripening; deposits of cast skins and honeydew also reduce the quality of the leaf. Disulfoton as applied in the seedbed for flea beetle control will also control the aphid. In the field, parathion, malathion, monocrotophos, or endosulfan can be applied as a spray or dust.

The white fly, Bemisia tabaci, also a Hemipteran, is common in Africa and the Far East. These small insects build up in large numbers on the underside of the leaf and cause damage similar to that of the green peach aphid. They are associated with transmission of a disease causing leaf curl. Malathion or parathion may be used for control.

Among the Thysanopterans is an important pest, Thrips tabaci, which causes serious damage in near-eastern and south-eastern European areas. It not only sucks plant juices causing silvery patches on the leaf but is responsible for spreading Spotted Wilt virus. It can be controlled with endosulfan, parathion, and methomyl.

If it is necessary to store cured tobacco any length of time it may become infested with the cigarette beetle, Lasioderma serricorne, or the tobacco moth, Ephestia elutella. If infestations are light it may be feasible to sort and destroy the infested tobacco. Heavy infestations of both insects can be controlled by fumigation under an airtight plastic sheet with methyl bromide. If the storage facilities are reasonably airtight, reinfestation can be prevented by hanging dichlorvos resin strips, 1 per 28.3 cubic meters of space.

Parathion, azinphosmethyl, endosulfan, methomyl, monocrotophos, disulfoton, and methyl bromide are extremely toxic and should be used only by or under the supervision of people who will read and follow the precautions on the label. Certain insecticides should not be used because of resulting excessive residues. These include DDT, TDE, arsenicals, toxaphene, benzene hexachloride, lindane, aldrin, dieldrin, heptachlor, strobane, chlordane, or endrin. If these are used on adjacent crops, care should be taken to avoid drift onto the tobacco field. Tobacco should not be grown in rotation with any crop on which benzene hexachloride is used since residues in the soil may produce off-flavor.

Insecticides should be used only as needed to avoid (1) unnecessary expense; (2) hazards to the applicator and other workers; (3) residues on the cured leaf; (4) kill of beneficial insects; and (5) contamination of the environment. If treatment is necessary during harvest, the material should be applied immediately after priming, rather than before, to reduce exposure of the workers.

When only Lepidopterous insects are involved the use of *B. thuringiensis* is highly desirable since it is essentially harmless to man and beneficial insects. In certain areas beneficial insects, if not suppressed by insecticides, will give adequate control of many of the pest species.

Several cultural practices can aid greatly in tobacco insect control. These include destruction of any crop residue immediately after harvest to destroy food for succeeding generations, turning up the roots and later discing the soil. These practices will also help control bacterial diseases and nematodes. Buildings in which tobacco is handled or stored temporarily should be kept free of any refuse when not in use to avoid the buildup of insects that attack cured tobacco. Tobacco should not be stored near feed, grain, seed, or other materials that might be infested. Alternate insect hosts near the seedbed or tobacco field should be avoided as far as possible to prevent buildup and movement of pests into the seedbed or tobacco field. Maintaining an intact seedbed cover will aid greatly in limiting infestations. Production of insect-free seedlings will prevent transport of pests to the field at transplanting time.

Topping the Growing Crop

Removal of the flower stalks is essential to production of marketable tobacco. This is done by breaking off the tops of the plants at about the third leaf below the flower head. This forces the plant to retain all plant substance in the leaves, rather than using it for flowering and seed production. Topping results in larger, thicker, and darker leaves that mature earlier and more uniformly. Topping should occur when about half the plants show flower heads, leaving 15 to 20 leaves on each plant.

Harvesting

Harvesting is done by one of two methods, by harvesting individual leaves as they mature, or by cutting the entire stalk with leaves attached. In the first method, the bottom 4 to 6 leaves are harvested soon after seed heads appear and the remaining leaves at weekly intervals over the following 4 to 6 weeks when yellow patches begin to appear on the leaves. This individual leaf harvest is sometimes called "priming", since each leaf is harvested when prime, or fully ripe. The leaves are strung on sticks (laths) 1 to 1½ meters long, by passing a string through each leaf base or by looping around the base of 2 to 5 leaves, and attaching a string of leaves to the 2 ends of the stick. A stick holds 60 or more leaves. These sticks are conveniently handled in curing sheds or barns.

In the second method, the plants are cut off, and a stick is thrust through the plant base, so that 6 to 8 stalks occupy a stick. These are transported to the curing shed or barn, and hung (with plants upside down) with spacing to facilitate good ventilation.

Curing

The curing procedure is highly important to production of marketable tobacco. Some of the same processes that take place during ripening continue during the early curing stages, but are hastened as the leaf is dehydrated. Initially, there is rapid destruction of chlorophyl and changes in the leaf compounds associated with respiration. Leaf lamina and stem are dried during the final stages. The objective is to produce a dried product that can be stored, handled, and marketed. The procedure varies with type of tobacco being produced. However, a period of "ordering" with low temperatures and high humidity followed so that the final moisture content of the leaf is restored to 20 to 25% by weight. This is the moisture content needed to make the leaves pliable for sorting and handling, and to foster desirable fermentation in bales or casks for the extended storage period that usually precedes ultimate manufacture of tobacco into the products sold to the consumer.

Air Curing

Air curing is widely practiced in the tropics. Such tobacco is equivalent to burley tobacco of temperate zone areas, but may be termed light or dark depending upon whether green or burley varieties are grown. Air curing is carried out in specially built barns or sheds, that may be kept closed at night and well ventilated in the daytime. No heat is used except during the extended periods of wet weather, when wood fires are made on earthen floors. The sticks of leaves are suspended at several successive tiers, spaced to give good ventilation within the shed. Cigar tobaccos are either stalk-cut or primed, and are-air cured in a similar manner to other dark types.

In tropical regions with long periods of dry, sunshiny weather at the harvest season, sun-curing is practiced. However, the quality of such tobacco is variable, it is not as marketable as other types, particularly for cigarettes. Sun-cured tobacco is generally consumed locally.

Flue-Curing for Bright Tobacco

This method is used to hasten the early curing stages, and then to complete the drying rapidly while the leaves still have a light yellow color. The crop for such curing should be grown with limited nitrogen fertilization to produce a light green colored leaf. To speed up the drying and killing stages of curing, a furnace is used to produce heat, and each furnace is equipped with a sheet-iron pipe extended through the barn to distribute the heat more uniformly. Careful control of temperature and humidity is achieved by continuous monitoring on an hour to hour basis. Flue-cured bright tobacco, low in nicotine is the predominant type used in blends for cigarettes.

Fire-Curing

This curing method allows the tobacco to yellow and wilt in the curing barn or shed without heat for three to five days, then to start slow wood fires on earthen floor as necessary to maintain temperatures of 35^{o}C to complete yellowing, after which temperatures are increased to 50^{o}C until the leaves are dry. The smoke from the open wood fires in the barn imparts a characteristic odor and taste to the tobacco that is in most demand for pipe smoking. Nicotine content is about the same as dark air-cured tobacco, much higher than in flue-cured tobacco.

Marketing

Tobacco is marketed on the basis of specific qualities of the leaf, and the color is only one factor. Thus some dark tobaccos are low in nicotine content, and others are high in nicotine. Flue-cured cigarette tobaccos are usually a light lemon-yellow color, and they are relatively low in nicotine, but air-cured cigarette tobacco is a light brown, quite acceptable in blends with flue-cured types. Color, texture of leaf and aroma are important characteristics. Uniformity greatly affects grade and price. In general, present day preferences of tobacco users have produced the highest prices for cigar wrapper, followed by the flue-cured and light air-cured types.

Tobacco is sometimes prepared for the initial marketing of the growers crop by packing in cases or bundles (or bales) weighing 15 to 30 kilos. Other markets accept tobacco leaf wrapped temporarily in burlap. This tobacco must be moist enough to be pliable and thus avoid serious losses from breakage. However, it is too moist for long term storage and export. After purchase, it is often sweated or fermented in bulk piles to complete processes begun during curing. Fermentation is induced by natural slow-acting chemical changes that tend to increase temperatures to 35° to 40°C, and result in losses of 5 to 10% in dry matter, and reduction in starch, sugar, nicotine and certain organic acids, and the development of a pleasing aroma. Fermentation may last for a year or more, before final manufacture into the end product.

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CONVERSION FACTOR

U.S. System		Metric System
	LENGTH	
0.394 inch, in	=	1 centimeter, cm
1 inch, in	=	2.54 centimeters, cm
1 foot, ft	=	0.305 meter, m
3.28 feet, ft	=	1 meter, m
1.094 yards, yd	=	1 meter, m
1 yard, yd (36 in)	=	0.914 meter, m
0.621 mile, mi	=	1 kilometer, km
1 mile, mi	=	1.61 kilometers, km
	AREA	
0.155 square inch, in^2	=	1 square centimeter, cm^2
1 square inch, in^2	=	6.45 square centimeters, cm^2
10.76 square feet, ft^2	=	1 square meter, m^2
1 square foot, ft^2	=	0.093 square meter, m^2
1.196 square yards, yd^2	=	1 square meter, m^2
1 square yard, yd^2	=	0.836 square meter, m^2
2.471 acres, acre	=	1 hectare, ha
1 acre (43,560 ft^2)	=	0.405 hectare, ha
0.3861 square mile, mi^2	=	1 square kilometer, km^2
1 square mile, mi^2	=	2.590 square kilometers, km^2
1 mi^2 (640 acres)	=	259 hectares, ha
	VOLUME	
0.061 cubic inch, in^3	=	1 cubic centimeter, cm^3
1 cubic inch, in^3	=	16.387 cubic centimeters, cm^3
1.057 quarts, qt (liquid)	=	1 liter, l
0.908 quart, qt (dry)	=	1 liter, l
1 quart, qt (liquid)	=	0.946 liter, l
1 British imperial quart	=	1.136 liters, l
2.838 bushels, bu	=	1 hectoliter, hl
1 bushel, bu	=	0.352 hectoliter, hl
3.532 cubic feet, ft^3	=	1 hectoliter, hl
1 cubic foot, ft^3	=	0.2832 hectoliter, hl
0.973 acre-inch	=	100 cubic meters, m^3
1 acre-inch	=	102.8 cubic meters, m^3

U.S. System		Metric System
	MASS	
0.0353 ounce, oz	=	1 gram, g
1 ounce, oz	=	28.349 grams, g
2.204 pounds, lb	=	1 kilogram, kg
1 pound, lb	=	0.454 kilogram, kg or 453.6 grams, g
220.46 pounds, lb	=	1 quintal, q
1 pound, lb	=	0.00454 quintal, q
2204.6 pounds, lb	=	1 metric ton
1.102 short tons (of 2000 lb)	=	1 metric ton
1 short ton (2000 lb)	=	0.907 metric ton
0.984 long ton (of 2240 lb)	=	1 metric ton
1 long ton (2240 lb)	=	1.016 metric tons
	YIELD or RATE	
0.892 pounds/acre	=	1 kilogram/hectare
1 pound/acre	=	1.121 kilograms/hectare
0.892 hundred weight (100 lb)/acre	=	1 quintal (metric)/hectare
1 hundred weight (of 100 lb)/acre	=	1.121 metric quintals/hectare
bu/acre x lb/bu x 0.01121	=	quintals per hectare, q/ha
0.446 short ton/acre	=	1 metric ton/hectare
1 short ton (2000 lb)/acre	=	2.242 metric tons/hectare
	TEMPERATURE	
Fahrenheit, F		Celsius or centigrade, C
degrees F	=	degrees C x 9/5 + 32° or 1.8C + 32
degrees, F-32 x 5/9 or .55556 (F-32)	=	degrees, C
0°F	=	-17.8 C
32°F (Freezing)	=	0°C
70°F	=	21.1°C
98.6°F (Body temperature)	=	37.0°C
212°F (Boiling)	=	100°C

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