Field Crop Production in Tropical Africa

by I.C. Onwueme and T.D. Sinha
The Technical Centre for Agricultural and Rural Co-operation (CTA) operates under the Lomé Convention between Member States of the European Community and the African, Caribbean and Pacific (ACP) States.

The aim of CTA is to collect, disseminate and facilitate the exchange of information on research, training and innovations in the field of agricultural and rural development and extension, for the benefit of the ACP States.

To achieve this aim, CTA commissions and publishes studies; organizes and supports conferences, workshops and courses; supports publications and translations; and offers an extensive information service.

Postal address:
Postbus 380, 6700 AJ Wageningen, Netherlands
Tel: (31) (0) (8380)-60400
Telex: (44)-30169 CTA NL
Telefax: (31) (0) (8380)-31052

Headquarters
‘de Rietkampen’
Galvanistraat 9
6716 AE, Ede
Netherlands

Published by:
CTA, Ede, The Netherlands
Field Crop Production in Tropical Africa
Principles and Practice

by

I.C. Onwueme and T.D. Sinha
DEDICATION

This book is dedicated with love and affection to our dear wives:

Teresa Onwueme
and
Manki Sinha
Published by:
Technical Centre for Agricultural and Rural Co-operation
ACP - EEC Lomé Convention

© 1991 Technical Centre for Agricultural and Rural Co-operation

ISBN No. 92 9081 086 6

Typeset and printed in England by
Michael Heath Ltd, Reigate, Surrey, RH2 9EL
# TABLE OF CONTENTS

**Preface**

**PART ONE – PRINCIPLES OF CROP PRODUCTION**

1. Origin and Development of Agriculture in Tropical Africa  
2. Climate of Tropical Africa  
3. Soil and Soil Fertility  
4. Soil Erosion and Conservation  
5. Plant Nutrition  
6. Irrigation and Drainage  
7. Cropping Systems  
8. Crop Establishment Practices  
9. Weeds and Weed Control

**PART TWO – PRACTICE OF CROP PRODUCTION**

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Cereal Crops</td>
<td>157</td>
</tr>
<tr>
<td></td>
<td>Maize</td>
<td>159</td>
</tr>
<tr>
<td></td>
<td>Sorghum</td>
<td>176</td>
</tr>
<tr>
<td></td>
<td>Millet</td>
<td>190</td>
</tr>
<tr>
<td></td>
<td>Rice</td>
<td>200</td>
</tr>
<tr>
<td></td>
<td>Wheat</td>
<td>215</td>
</tr>
<tr>
<td></td>
<td>Barley</td>
<td>225</td>
</tr>
<tr>
<td>11</td>
<td>Roots and Tubers</td>
<td>233</td>
</tr>
<tr>
<td></td>
<td>Cassava</td>
<td>233</td>
</tr>
<tr>
<td></td>
<td>Yams</td>
<td>250</td>
</tr>
<tr>
<td></td>
<td>Sweet Potatoes</td>
<td>267</td>
</tr>
<tr>
<td></td>
<td>Cocoyams</td>
<td>276</td>
</tr>
<tr>
<td>12</td>
<td>Grain Legumes</td>
<td>289</td>
</tr>
<tr>
<td></td>
<td>Cowpeas</td>
<td>292</td>
</tr>
<tr>
<td></td>
<td>Common (Field) Beans</td>
<td>299</td>
</tr>
<tr>
<td></td>
<td>Pigeon Peas</td>
<td>305</td>
</tr>
<tr>
<td></td>
<td>Field and Garden Peas</td>
<td>311</td>
</tr>
<tr>
<td></td>
<td>Chick Peas</td>
<td>315</td>
</tr>
<tr>
<td>13</td>
<td>Oil-seed Crops</td>
<td>321</td>
</tr>
<tr>
<td></td>
<td>Groundnuts</td>
<td>324</td>
</tr>
<tr>
<td></td>
<td>Soybeans</td>
<td>337</td>
</tr>
<tr>
<td></td>
<td>Sesame</td>
<td>344</td>
</tr>
<tr>
<td>14</td>
<td>Fibre Crops</td>
<td>375</td>
</tr>
<tr>
<td></td>
<td>Sunflowers</td>
<td>349</td>
</tr>
<tr>
<td></td>
<td>Safflowers</td>
<td>355</td>
</tr>
<tr>
<td></td>
<td>Castor</td>
<td>359</td>
</tr>
<tr>
<td></td>
<td>Oil Palms</td>
<td>363</td>
</tr>
<tr>
<td></td>
<td>Cotton</td>
<td>377</td>
</tr>
<tr>
<td></td>
<td>Kenaf and Roselle</td>
<td>387</td>
</tr>
<tr>
<td></td>
<td>Hemp</td>
<td>391</td>
</tr>
<tr>
<td></td>
<td>Sisal</td>
<td>394</td>
</tr>
<tr>
<td>15</td>
<td>Sugar Crops</td>
<td>340</td>
</tr>
<tr>
<td></td>
<td>Sugarcane</td>
<td>402</td>
</tr>
<tr>
<td>16</td>
<td>Drug Crops</td>
<td>415</td>
</tr>
<tr>
<td></td>
<td>Tobacco</td>
<td>416</td>
</tr>
<tr>
<td>17</td>
<td>Beverage Crops</td>
<td>429</td>
</tr>
<tr>
<td></td>
<td>Tea</td>
<td>430</td>
</tr>
<tr>
<td></td>
<td>Coffee</td>
<td>438</td>
</tr>
<tr>
<td></td>
<td>Cocoa</td>
<td>447</td>
</tr>
<tr>
<td>18</td>
<td>Latex Crops</td>
<td>455</td>
</tr>
<tr>
<td></td>
<td>Para Rubber</td>
<td>456</td>
</tr>
</tbody>
</table>

References and Bibliography 463  
Index 469
PREFACE

The present critical situation in world food supplies, especially in the developing countries, demands that all available agricultural resources be utilized to the full to maximize food production through improved agronomy: better soil management and crop husbandry; the use of improved seed and fertilizers; the efficient use of water; effective weed control; and effective crop-protection measures. Most governments in tropical Africa have given substantial encouragement to field crop production, but the study and practice of crop production is in a constant state of change. Within the last two decades, scientific research has progressed rapidly in most countries of Africa, but valuable research achievements in crop production are generally published in scientific journals of agriculture, which are not easily available to students in schools, universities and colleges of agriculture.

The aim of this book is to bring the results of scientific research and progress in crop production within the easy reach of students of agriculture, and to provide a comprehensive text for an introductory course in field crop production. It combines detailed treatment of agronomic principles with a crop-by-crop treatment of the major field crops of tropical Africa. Efforts have been made to present the subject in a systematic way and in simple language, and hopefully this textbook will meet the requirements of such courses. The book has attempted to cover the field crops of major importance in tropical Africa, but some of the important plantation crops such as oil palm and cocoa have also been covered. Though the book is mainly written for undergraduate students, it may also be useful to postgraduate students of agronomy, research workers, agricultural assistants, agricultural extension officers and progressive farmers.

The authors will be pleased to know if the book has served the purpose for which it was written, and would be glad to receive comments and suggestions for further improvement.

The authors wish to express their gratitude to Professor J.Y. Yayock, Head, Agronomy Department, and Professor M.K. Moolani of the Agronomy Department, Ahmadu Bello University, Zaria (Nigeria), for providing periodic guidance and the opportunity to undertake this work. Finally, the encouragement and assistance received from our colleagues is deeply appreciated. The authors are greatly indebted to all who have made material available for illustrations.
PART ONE

Principles of Crop Production
ORIGIN AND DEVELOPMENT OF AGRICULTURE IN TROPICAL AFRICA

INCIPIENT AGRICULTURE
Africa is the largest continent in the world. The name Africa is derived from the Roman word Aourigha (pronounced Africa) which they used for the Berber inhabitants of the region lying between Cyrenaica and Mauritania. Africa covers an area of about 30 million km², approximately 20% of all the earth's land surface. From east to west it stretches 7,200 km, very comparable with the north-south extent of 8,000 km. Tropical Africa is that part of the continent lying between the Tropics of Cancer and Capricorn, i.e. 23.5° north and south of the equator. It covers an area of about 23 million km², approximately 76% of the total land surface of the continent (Fig. 1).

The earliest man probably lived about 2 million years ago, but there were no agricultural communities until about 11,000 years ago. The oldest remains of human dwellings were found in the Border Cave of Zululand in southern Africa, dating from about 47,000 BC; Howieson’s Poort near Montagu in the Cape Province, dating from about 43,000 BC; and the Nile Valley of Upper Egypt, dating from between 15,000 and 10,500 BC. These sites show no evidence of plant or animal domestication. The human dwellings suggest that early man was a hunter of small animals and birds and a gatherer of plants. As the population increased, early man must have found it difficult to obtain enough food from gathering, hunting and fishing and this probably led to the practice of agriculture, which is the deliberate tending of crops and rearing of animals for human use. The change-over from hunter-gatherer to full-time agriculturalist must have been very gradual and this stage might be called 'incipient' agriculture.
A search for the geographical distribution of centres of plant domestication cannot be carried out without studying the origin and spread of agriculture. Sites of early farms have been discovered in Thailand, the Near East and Mexico. They show that incipient agriculture existed in Thailand in about 11,000 BC, in the Near East in about 9,000 BC and in Mexico in about 6,000 BC. No such sites have been found in other areas and at present it is accepted that from these cradles of agriculture, the practice spread to other parts of the world. Agriculture may have spread to China, Japan and South-East Asia from Thailand, while it may have spread to West Asia, South-West Asia, South Asia, the Nile Valley and Europe from the Near East. From the Nile Valley, agriculture had spread southwards and westwards through Africa to the Sudan region by about 3,500 BC. Although the knowledge of agricultural crops and methods probably spread into West Africa from the north and east, the cultivation of certain crops, such as cotton and millet, may have developed independently in the Sudan region. Agriculture was developing in parts of central and southern Africa by about 1,500 to 1,000 BC. In
some parts of the continent, however, there was no agriculture until much later, as for example in some regions of dense forest and dry desert, where conditions are unsuitable.

ORIGIN OF CULTIVATED CROPS
All cultivated crop plants were domesticated from their wild species. These species were adapted to the needs of man before the dawn of recorded history. For agricultural research, especially plant breeding, it is very valuable to know their places of origin, their centres of genetic diversity and their wild and weed relatives. Most of the domesticated crops were introduced into new areas far from their centre of origin by migrating human populations in prehistoric as well as in recorded times. As a result, both indigenous and introduced crops are grown everywhere in the world.

Alphonse de Candolle was the first scientist to engage in tracing the origin of cultivated plants. In his book *Origin des plantes cultivées*, published in 1882, he concluded that the region where a species is abundant is not necessarily its centre of origin. Perhaps de Candolle was the first scientist to indicate regions where the earliest plant domestication might have taken place. According to him, agriculture came originally from three great regions: China; the vast region which stretches from the Ganges to Armenia and the Nile (i.e. South-West Asia and Egypt); and tropical America (the highlands of Mexico and Peru).

Centres of Origin of Crop Plants
After de Candolle, Nicolai Ivanovic Vavilov (1926) concluded that a centre of origin was characterized by dominant alleles while towards the periphery of the centre, the frequency of recessive alleles increased and the genetic diversity decreased. He continued to work on his concept of ‘gene centres’ and in 1945 he finally reported the following centres of origin:

* China
* India/Indo-Malaya
* Central Asia, including North-West India, Pakistan, Afghanistan and Turkestan (USSR)
* Near East
* Mediterranean Sea coastal and adjacent regions
* Ethiopia
* South Mexico and Central America
* South America (Peru, Ecuador, Bolivia)/Isle of Chiloe (Chile).

These regions all lie between 20° and 45° latitude in mountainous regions, and often in areas with a temperate climate. They are
separated by great deserts. According to Vavilov, agriculture developed independently in these eight regions, as evidenced by the differences in agricultural methods, implements and domestic animals.

In 1962, Porteres reported the following centres of agriculture in Africa south of the Sahara (Porteres, 1962):

* West Africa
  a Tropical Sector
    i Senegambian subsector
    ii Central Niger subsector
    iii Caad-Nilotic subsector
  b Subequatorial Sector
* Nilo-Abyssinian
  a Nilotic Sector
  b Abyssinian Sector
* East African
* Central African

The last two centres were not elaborated by Porteres. The claim for African centres of agriculture has been refuted by Clark (1963) and Harris (1972). Harris concluded that the typically West African crops are local additions to an intrusive agricultural complex, rather than compounds of ancient indigenous ones.

In 1968, Zhukovsky heralded his concept of 'megagene centres'. According to him, these are the 12 megacentres:

* China
* Indo-China, Indonesia
* Australia, New Zealand
* Indian subcontinent
* Central Asia
* West Asia
* Mediterranean coastal and adjacent regions
* Africa/Ethiopia
* Europe, Siberia
* Central America
* Bolivia, Peru, Chile
* North America

**Contribution of Different Centres**

Based on the findings of Vavilov (1945) and Zhukovsky (1970), the following are the important crops that originated in the different centres. For some crops more than one centre has been reported; the second one may be the secondary centre of origin of the crop.
Chinese centre
China is one of the richest regions, contributing to many important crops such as *Brassica campestris* and related species. *Camellia sinensis, Colocasia esculenta, Corchorus sinensis, Glycine max, Panicum miliaceum, Raphanus sativus* and *Setaria italica*. It is a secondary centre for *Oriza sativa* spp. *japonica, Zea mays* and other crops.

Indo-Malayan centre
This region is important for crops such as *Cocos nucifera, Colocasia esculenta, Dioscorea* spp., wild *Oryza* spp. and *Saccharum officinarum*.

Indian centre
Important crops from this region are: *Oryza sativa, Phaseolus mungo, Piper* spp., *Saccharum sinensis, Vigna sinensis* and *Cucurbita sativa*.

Central Asian centre
*Allium cepa, A. sativum, Daucus carota, Lathyrus sativus, Spinacea oleracea* and *Vicia faba* are important crops from this centre.

Near Eastern centre
This is the centre for *Brassica oleracea, Hordeum vulgare, Lens esculenta, Medicago* spp., *Secale* spp., *Triticum* spp., *Vicia sativa* and *Vitis vinifera*.

Georgia (USSR) is a secondary centre of diversity for *Glycine max, Lupinus albus, Phaseolus vulgaris, Setaria italica* and *Zea mays*.

Mediterranean centre
Many crops have been domesticated in this region: *Avena* spp., *Beta vulgaris, Brassica napus, B. oleracea, Lathyrus* spp., *Linum usitatissimum, Lolium* spp., *Lupinus* spp., *Olea europaea, Raphanus sativus, Trifolium* spp. and *Vitis vinifera*.

Ethiopian or African centre
Central American and Mexican centre
Only a few (but important) crops were domesticated in this region: 
*Agave* spp., *Capsicum* spp., *Cucurbita* spp., *Gossypium* spp., 
*Ipomeae batatas*, *Phaseolus* spp. and *Zea mays*.

South American centre
This is the primary centre of origin of a number of tuberous crops 
such as *Oxalis tuberosa*, *Solanum* spp., and *Ullucus tuberosus*. 
Other crops from this centre are *Amaranthus* spp., *Arachis hypogeae*, 
*Capsicum* spp., *Cucurbita maxima*, *Gossypium* spp., *Hevea* 
spp., *Lupinus* spp., *Lycopersicum* spp., *Manihot esculenta*, *Nicotiana* 
spp., *Phaseolus* spp., *Solanum* spp. and *Theobroma cacao*. It is 
a secondary centre of diversity for *Zea mays*.

DISPERAL OF DOMESTICATED CROPS
The dispersal of crop plants from their centre of origin to other parts 
of the world was either natural or through the agency of man. 
Coconuts may have floated across the Pacific Ocean from Asia to the 
western coast of Central America, and perhaps the capsules of sweet 
potatoes crossed the Pacific in the same way. These are some 
examples of the natural dispersal of crops.

The dispersal of crop plants by man must have taken place in 
several phases. At the early stages in the domestication of crops they 
spread with the expansion and migration of primitive agricultural 
communities. A second and more important phase in crop dispersal 
was associated with very early trade, with conquests and with the 
more widespread human migrations taking place between the different 
parts of the Old World.

The third and most important phase in the history of crop dispersal 
began with attempts by Europeans to find a sea route to India. 
During the fifteenth century, Europeans not only explored the 
routes to India, China and other countries of Asia, but also discovered 
the Americas. These explorations and discoveries were followed by 
greatly expanded world trade. Most of the important tropical crops 
were dispersed to various parts of the world during the sixteenth 
and seventeenth centuries. During the sixteenth century, New 
World crops (i.e. crops indigenous to the Americas) such as maize, 
groundnuts, sweet potatoes, potatoes, tomatoes and cassava, were 
spread to other parts of the tropics. During the eighteenth and 
nineteenth centuries, the development of agricultural enterprises in 
the tropics was stimulated by the demand from Europe for 
agricultural raw materials for use in industry. As a result of these
developments, many crops spread from one area to the other. For example: rubber from Brazil became popular in Malaysia, Sri Lanka and West Africa; American cotton became popular in the Old World and sugarcane became an economic crop of the New World.

The most recent developments in the dispersal of crops have been associated with the expansion of agricultural research with international cooperation. This has included the exchange of seeds, or even the exchange of large collections of germ plasm, between agricultural researchers in different parts of the world.

CROPS GROWN IN AFRICA

Indigenous Crops of Africa
Africa possesses relatively few indigenous plants of outstanding economic value. The most important indigenous food, commodity and other economic plants are:

* Cereals
  Bulrush millet
  Guinea corn
  Finger millet
  Rice
  Hungry rice

* Grain legumes
  Cowpea
  Pigeon pea

* Yams
  White guinea yam
  Yellow guinea yam

* Oil-seeds
  Oil palm
  Niger seed
  Castor
  Bambarra groundnut

* Fibre crops
  Cotton
  Kenaf
  Bow-string hemp
  Kapok

* Coffee
  Coffee

* Kolanut
  Gbanja Kola
  Abata Kola

* Watermelon
  Citrullus lanatus
Introduced Crops Grown in Africa
Besides the above indigenous crops, there are many introduced crops which have been accepted and are grown on a large scale. Important among these are:

* Cereals
  - Rice
  - Wheat
  - Oryza sativa
  - Triticum aestivum
  - Arachis hypogaea

* Grain legumes
  - Groundnut
  - Field (common) bean
  - Phaseolus vulgaris
  - Pisum spp.

* Roots and tubers
  - Cassava
  - Cocoyam or dasheen
  - Greater yam or water yam
  - Manihot esculenta
  - Colocasia esculenta
  - Dioscorea alata

* Oil-seeds
  - Sesame
  - Gossypium
  - Sesamum indicum
  - G. barbadense,
  - Xanthosoma sagittifolium
  - Ipomoea batatas

* Fibre crops
  - Cotton
  - G. hirsutum

* Sugar crop
  - Sisal
  - Agave sisalana
  - Sugarcane
  - Saccharum officinarum

* Drug crop
  - Tobacco
  - Nicotiana tabaccum

* Beverage crops
  - Tea
  - Camellia sinensis
  - Cocoa
  - Theobroma cacao

* Latex crops
  - Para rubber
  - Hevea brasiliensis

CLASSIFICATION OF CROP PLANTS
There are two major methods of classifying crop plants; one is the 'botanical classification' based upon morphological similarity of plant parts and the other is the 'economic classification' based upon their usage. In this book only the second method is used.

Economic Classification
The economic classification of crop plants is based on their use. Since some crops may have several uses, it follows that certain crops may belong to more than one category in this classification. On the basis of use, the following major classes can be distinguished.

Cereal/grain
These crops belong the the grass family (Gramineae) and are grown for their edible seeds. They include rice, wheat, barley, maize, sorghum (guinea corn) and millet, which are the major cereals.
Other minor millet crops such as finger millet and teff also belong to this large family.

**Grain legumes**
These belong to the family Leguminosae and are grown for their edible seeds. They include cowpeas, soybeans, groundnuts, field peas, beans, lentils and pigeon peas.

**Root and tuber crops**
These are grown for their enlarged roots or tubers. Important root and tuber crops are cassava, sweet potatoes, potatoes, yams and cocoyams.

**Fibre crops**
Crops grown for fibre include cotton, jute, kenaf, hemp, ramie and sisal.

**Oil crops**
The crops grown for edible oil include groundnuts, soybeans, sesame, sunflowers, safflowers, rape-mustard and linseed. Cotton seed and maize are also important sources of edible oil. Castor beans are grown for non-edible oil.

**Sugar crops**
These are sugarcane and, in temperate regions, sugar beet.

**Drug crops**
These crops are smoked or chewed for their stimulating effect. They include tobacco and ‘bhang’ (*Cannabis sativa*).

**Beverage crops**
These crops are also a source of stimulants. They include tea, coffee and cocoa.

**Latex crops**
These crops, such as Para rubber, are grown for the milky sap, or latex, which they produce.

**Vegetable crops**
This group includes potatoes, tomatoes and onions.

**Forage crops**
These crops are grown as feed for ruminants. They are fed to the animals either fresh or in dried form, such as hay and silage.
Table 1  Crop statistics for the world and Africa during 1961–5, 1979 and 1989; percentage increase in production during 1979 and 1989 over 1961–5; and African share in world production.

<table>
<thead>
<tr>
<th>Crop Year</th>
<th>Area</th>
<th>Yield</th>
<th>Production</th>
<th>Percentage increase</th>
<th>Area</th>
<th>Yield</th>
<th>Production</th>
<th>Percentage increase</th>
<th>African production</th>
</tr>
</thead>
<tbody>
<tr>
<td>WORLD</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1961–5</td>
<td>670.6</td>
<td>14460</td>
<td>987.5</td>
<td>57.3</td>
<td>59.0</td>
<td>856</td>
<td>50.5</td>
<td>31.7</td>
<td>4.28</td>
</tr>
<tr>
<td>1979</td>
<td>760.9</td>
<td>2042</td>
<td>1533.1</td>
<td>88.9</td>
<td>72.4</td>
<td>918</td>
<td>66.5</td>
<td>31.7</td>
<td>4.06</td>
</tr>
<tr>
<td>1989</td>
<td>704.7</td>
<td>2646</td>
<td>1864.0</td>
<td>88.9</td>
<td>74.0</td>
<td>1228</td>
<td>90.8</td>
<td>79.8</td>
<td>4.86</td>
</tr>
<tr>
<td>Wheat</td>
<td>210.5</td>
<td>1209</td>
<td>254.5</td>
<td>57.3</td>
<td>7.7</td>
<td>833</td>
<td>50.5</td>
<td>31.7</td>
<td>4.28</td>
</tr>
<tr>
<td>1979</td>
<td>238.7</td>
<td>1782</td>
<td>455.5</td>
<td>79.0</td>
<td>8.4</td>
<td>1069</td>
<td>50.5</td>
<td>31.7</td>
<td>4.28</td>
</tr>
<tr>
<td>1989</td>
<td>226.0</td>
<td>2381</td>
<td>538.1</td>
<td>111.4</td>
<td>8.6</td>
<td>1536</td>
<td>50.5</td>
<td>31.7</td>
<td>4.28</td>
</tr>
<tr>
<td>Rice</td>
<td>124.2</td>
<td>2038</td>
<td>253.2</td>
<td>50.0</td>
<td>3.2</td>
<td>1713</td>
<td>50.5</td>
<td>31.7</td>
<td>4.28</td>
</tr>
<tr>
<td>1979</td>
<td>145.3</td>
<td>2615</td>
<td>379.8</td>
<td>100.0</td>
<td>4.8</td>
<td>1827</td>
<td>50.5</td>
<td>31.7</td>
<td>4.28</td>
</tr>
<tr>
<td>1989</td>
<td>146.5</td>
<td>3457</td>
<td>506.3</td>
<td>100.0</td>
<td>5.5</td>
<td>1899</td>
<td>50.5</td>
<td>31.7</td>
<td>4.28</td>
</tr>
<tr>
<td>Barley</td>
<td>68.0</td>
<td>1466</td>
<td>99.7</td>
<td>19.2</td>
<td>5.0</td>
<td>706</td>
<td>50.5</td>
<td>31.7</td>
<td>4.28</td>
</tr>
<tr>
<td>1979</td>
<td>67.4</td>
<td>1761</td>
<td>118.8</td>
<td>19.2</td>
<td>5.2</td>
<td>743</td>
<td>50.5</td>
<td>31.7</td>
<td>4.28</td>
</tr>
<tr>
<td>1989</td>
<td>72.0</td>
<td>2348</td>
<td>169.0</td>
<td>69.5</td>
<td>5.0</td>
<td>1149</td>
<td>50.5</td>
<td>31.7</td>
<td>4.28</td>
</tr>
<tr>
<td>Maize</td>
<td>99.6</td>
<td>2170</td>
<td>216.1</td>
<td></td>
<td>14.6</td>
<td>1092</td>
<td>15.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1979</td>
<td>120.5</td>
<td>3271</td>
<td>394.2</td>
<td></td>
<td>20.9</td>
<td>1145</td>
<td>23.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1989</td>
<td>129.7</td>
<td>3627</td>
<td>470.3</td>
<td>117.6</td>
<td>20.9</td>
<td>1742</td>
<td>36.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sorghum</td>
<td>30.6</td>
<td>918</td>
<td>35.5</td>
<td></td>
<td>11.7</td>
<td>730</td>
<td>8.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1979</td>
<td>50.9</td>
<td>1322</td>
<td>67.3</td>
<td></td>
<td>14.1</td>
<td>691</td>
<td>9.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1989</td>
<td>44.4</td>
<td>1305</td>
<td>56.0</td>
<td></td>
<td>17.0</td>
<td>825</td>
<td>14.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Millet</td>
<td>66.4</td>
<td>572</td>
<td>38.0</td>
<td></td>
<td>13.8</td>
<td>648</td>
<td>8.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1979</td>
<td>53.2</td>
<td>620</td>
<td>33.0</td>
<td></td>
<td>16.6</td>
<td>581</td>
<td>9.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1989</td>
<td>37.5</td>
<td>814</td>
<td>30.5</td>
<td></td>
<td>14.3</td>
<td>652</td>
<td>9.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roots &amp; tubers</td>
<td>49.9</td>
<td>9868</td>
<td>491.8</td>
<td></td>
<td>9.6</td>
<td>6168</td>
<td>59.4</td>
<td></td>
<td>31.7</td>
</tr>
<tr>
<td>1979</td>
<td>49.9</td>
<td>10982</td>
<td>547.5</td>
<td>11.3</td>
<td>12.1</td>
<td>6764</td>
<td>59.4</td>
<td></td>
<td>38.0</td>
</tr>
<tr>
<td>1989</td>
<td>46.8</td>
<td>12806</td>
<td>590.2</td>
<td>20.0</td>
<td>14.2</td>
<td>7231</td>
<td>102.6</td>
<td></td>
<td>72.7</td>
</tr>
<tr>
<td>Year</td>
<td>Pulses</td>
<td>Groundnuts</td>
<td>Soybeans</td>
<td>Sunflower</td>
<td>Sesame</td>
<td>Safflower</td>
<td>Castor</td>
<td>Sugarcane</td>
<td></td>
</tr>
<tr>
<td>--------</td>
<td>--------</td>
<td>------------</td>
<td>----------</td>
<td>-----------</td>
<td>--------</td>
<td>-----------</td>
<td>--------</td>
<td>-----------</td>
<td></td>
</tr>
<tr>
<td>1961-5</td>
<td>68.2</td>
<td>18.3</td>
<td>20.4</td>
<td>7.0</td>
<td>5.6</td>
<td>0.7</td>
<td>1.4</td>
<td>9.3</td>
<td></td>
</tr>
<tr>
<td>1979</td>
<td>75.5</td>
<td>10.9</td>
<td>19.7</td>
<td>7.0</td>
<td>12.0</td>
<td>1.5</td>
<td>1.4</td>
<td>13.5</td>
<td></td>
</tr>
<tr>
<td>1989</td>
<td>70.0</td>
<td>20.1</td>
<td>16.6</td>
<td>5.6</td>
<td>7.0</td>
<td>1.3</td>
<td>1.5</td>
<td>16.7</td>
<td></td>
</tr>
</tbody>
</table>

| |  |  |  |  |  |  |  |  |
| 42.3 | 15.8 | 32.5 | 7.3 | 13.2 | 2.4 | 0.4 | 0.9 |
| 51.9 | 19.2 | 94.2 | 7.3 | 13.2 | 1.0 | 1.2 | 0.9 |
| 58.0 | 22.6 | 107.4 | 7.3 | 13.2 | 19.0 | 1.2 | 1.2 |
| 37.1 | 42.6 | 230.6 | 7.3 | 13.2 | 39.0 | 1.2 | 1.2 |
| 11.3 | 5.8 | 0.4 | 7.3 | 0.4 | 1.0 | 0.4 | 0.4 |
| 584 | 790 | 1212 | 7.3 | 7.3 | 320 | 7.3 | 7.3 |
| 6.6 | 4.6 | 0.2 | 7.3 | 0.2 | 1.0 | 7.3 | 7.3 |
| 2.3 | 1.8 | 0.2 | 7.3 | 0.2 | 1.0 | 7.3 | 7.3 |
| 3.9 | 5.3 | 0.06 | 7.3 | 0.06 | 0.37 | 7.3 | 7.3 |
| 5.1 | 5.5 | 0.24 | 7.3 | 0.24 | 0.49 | 7.3 | 7.3 |
| 31.7 | 3.7 | 0.53 | 7.3 | 0.53 | 0.49 | 7.3 | 7.3 |
| 9.84 | 28.72 | 265.0 | 7.3 | 265.0 | 33.3 | 265.0 | 7.3 |
| 11.37 | 20.37 | 0.25 | 7.3 | 0.25 | 23.58 | 0.25 | 7.3 |
| 0.50 | 2.75 | 0.50 | 7.3 | 2.75 | 25.17 | 0.50 | 7.3 |
| 0.37 | 0.49 | 0.50 | 7.3 | 0.49 | 23.58 | 0.50 | 7.3 |
| 0.71 | 0.50 | 0.49 | 7.3 | 0.50 | 23.58 | 0.50 | 7.3 |
| 0.12 | 0.49 | 0.50 | 7.3 | 0.49 | 23.58 | 0.50 | 7.3 |
| 0.42 | 0.49 | 0.50 | 7.3 | 0.49 | 23.58 | 0.50 | 7.3 |
| 0.42 | 0.49 | 0.50 | 7.3 | 0.49 | 23.58 | 0.50 | 7.3 |
| 245.7 | 33.3 | 706.1 | 7.3 | 245.7 | 60.4 | 706.1 | 7.3 |
| 3.25 | 23.58 | 0.50 | 7.3 | 3.25 | 23.58 | 0.50 | 7.3 |
| 2.75 | 2.75 | 0.50 | 7.3 | 2.75 | 2.75 | 0.50 | 7.3 |

Sources: FAO Production Yearbook, Vols 29, 33 and 34
Forage crops include grasses, legumes, crucifers and other crops used for fodder, hay or silage. The important fodder crops are maize, guinea corn, cowpeas, guinea grass and elephant grass.

PRESENT POSITION OF AGRICULTURE IN AFRICA
Most countries in Africa are predominantly agricultural and it is now recognized that increasing the productivity of their agriculture is essential to their economic development. Agriculture in these countries is diverse and presents a corresponding diversity of development problems.

The report *Africa 2000*, by the Organization of Economic Cooperation and Development (OECD), predicts that Africa will only manage to feed 65% of its fast-growing population by the end of the century, unless radical changes take place. In many countries the rate of population growth is 2.5–3.5% per annum. This prediction makes it imperative that everyone involved in agriculture must take action now and suggest dynamic approaches to the problems faced in agriculture.

![Graph showing area and production of total cereals in the world](image-url)
If all African countries make some serious efforts to increase agricultural production, they can achieve self-sufficiency in food production. The successes with the 'miracle' rice emanating from the International Rice Research Institute (IRRI) and 'Mexican' wheat from the International Centre for Wheat and Maize Improvement (CIMMYT), clearly demonstrate that great advances are possible. The extension of the basic lessons learned with rice and wheat to the other major food crops and to other crops grown in rotation for cash sales, could transform the economic status of the developing nations and the welfare of their rural populations.

The crop statistics of the world and Africa during 1961–1965, 1979 and 1989 are presented in Table 1. There has been very satisfactory achievement in raising the production of important crops in many countries. The comparative figures of production and the percentage of increase in the production reveal that the countries of Africa lag far behind in their production level in comparison with the other countries of the world. Many countries are trying very hard to achieve self-sufficiency in food production.

![Figure 3: Area and production of total cereals in Africa](image)
Fig. 4  Production percentage of different cereals in the world in 1989

Fig. 5  Production percentage of different cereals in Africa in 1989
2

CLIMATE OF TROPICAL AFRICA

Crop growth and production depend on the genetic constitution of the plant, soil characteristics, and the climate in which the plant grows. Climate is defined as the aggregate of all the external conditions and influences affecting the life and development of organisms. Climate has an important influence on the nature of the natural vegetation, the characteristics of the soil, the crops that can be grown and the type of farming that can be practised in any region.

ELEMENTS OF CLIMATE
The climate of any region is composed of a great variety of elements and it is very unlikely that two different places can have an identical climate. The following are the major elements of climate:

* rainfall
* solar radiation, sunshine, light and cloudiness
* temperature
* humidity
* wind.

Rainfall
Rainfall is the most important climatic factor influencing agriculture in the tropics, as it has the biggest effect in determining the potential of any area; the crops which can be grown, the farming system, and the sequence and timing of farming operations. For agriculture, it is not only the total amount of rainfall per annum that is important, but also its seasonal distribution, its variability, its reliability within and between seasons, its intensity and rate of infiltration into the soil, and the balance between rainfall and evapotranspiration (loss of water through evaporation and transpiration).

Rainfall variability
Rainfall in the tropics is generally more variable than in the temperate areas. Variability is particularly important in semi-arid areas
where droughts such as those experienced in 1973 and 1979 in the Sahel region of north Africa cause great harm. In any dry area, a few years of low rainfall can lead to a deterioration in vegetation which cannot always be reversed in succeeding years of high rainfall. A decrease in protective vegetation cover in dry years makes an area more susceptible to flooding and erosion when wetter conditions arise, and the deterioration may then be accelerated.

In areas with marked seasonal regimes, variability at the start and end of the rains is particularly important. There are certain periods in the growing season when lack of water becomes critical for growth. In the Symposium on Drought in Africa, Dalby and Harrison Church (1973) pointed out that in northern Nigeria even ‘drought resistant’ crops could not produce any yield in 1972 because the three or four weeks of drought occurred at a time when the crops were in the grain formation stage. Drought conditions may occur when rains are late or when a dry period occurs in early, mid or late season.

Rainfall distribution, reliability and intensity
Average rainfall figures are of little practical value, except as a broad generalization to indicate the types of vegetation and cultivation likely to be found. Distribution and reliability are more crucial factors. Year-to-year variability in rainfall is extremely large and important in the tropics; in extreme cases it may range from 20–250% of the mean.

The high average rainfall figures for wet equatorial and seasonal climatic areas (discussed in the second half of this chapter) may lead one to believe that no crop moisture stress is likely to occur in these areas, but severe drought periods, sometimes lasting for a few weeks, frequently occur during the rainy seasons and affect crop yields. It is a general rule, however, that the drier the climate, the less reliable is the rainfall. The dry and arid regions are characterized by considerable variability both in the annual amount of rainfall and its distribution during the season.

In most parts of the tropics a large proportion of the rainfall is in the form of heavy showers with storms of high intensity. Evans (1958) found that at Masasi in southern Tanzania, 45% of the annual rainfall fell in heavy showers and storms of more than 25 mm/day. At Namulonge in Uganda in 1950/1, 25% of the storms had peak rates greater than 90 mm/hour, 9.4% had a peak rate of 140 mm/hour, and a maximum peak intensity of 250 mm/hour was recorded (Farbrother and Manning, 1952). Adu (1972) stated that rainfall intensities exceeding 250 mm/hour for short periods are not unusual in Ghana. In a storm at Samaru (Nigeria) in 1969, 155
mm/hour fell in two hours with a peak intensity of 290 mm/hour and an intensity range of 120–216 mm/hour maintained for 25 minutes (Kowal, 1970a). Peak intensities can be much higher, as shown by data from some individual storms at Bambey in Senegal; on 12 July 1861, 37 mm in 3 minutes (740 mm/hour); on 29 July 1961, 18 mm in 3 minutes (360 mm/hour); and on 2 September 1961, 33.5 mm in 6 minutes (335 mm/hour) (Jones and Wild, 1975). These are figures for exceptionally violent storms.

While storms of such violence are quite rare at any one place, they are undoubtedly an important feature of the wet tropical and seasonal climatic regions. The raindrops of high intensity storms break up the soil aggregates and block the soil pores with fine soil particles. They cause the soil surface to become sealed, thus greatly reducing the infiltration of rain-water, with the result that run-off and erosion are increased, and the proportion of rainfall that percolates into the soil is reduced.

**Rainfall and plant growth**

Success in growing a crop depends on the balance between the amount of water stored in the soil and the loss of water by evapotranspiration. The amount of water stored in the soil depends on the total rainfall, the amount of water infiltrated into the soil, and the amount retained in the soil. Evapotranspiration is also very variable and depends on climate, moisture supply, vegetation cover and mulching. In the dry areas of tropical Africa, annual potential evapotranspiration (ET) is almost always greater than the annual rainfall (P). Even in the seasonal climatic zones, ET is higher than P. In these zones, ET tends to increase with distance from the equator. For Senegal, Charreau and Nicou (1971) quoted the range of 1,500–2,220 mm per annum, with the ratio of P:ET decreasing from about 0.8 in the south to 0.2 in the north. The pattern is similar across the whole of the northern savanna. The narrower the ratio, the greater will be the moisture stress in the root zone and the greater will be the damage to crop growth.

Although potential ET may be greater than P on an annual basis, there is almost everywhere a period of water surplus in most years when P temporarily exceeds ET. Cocheme and Franquin (1967) calculated the water surplus (P-ET) for 35 stations in the seasonal and dry climatic zones based on the mean of 30 years’ data. They reported that the total water surplus and the period over which is is spread depends more on P than on ET, and therefore decreases with decreasing rainfall. However, the greater the spread of rainfall during the year, the smaller the surplus. For example, Kaduna with an annual rainfall of 1,298 mm falling over 10 months (February–
November) has a water surplus of 542 mm spread over four months (June–September), whereas Ilorin with a similar annual rainfall over a period of 12 months has a surplus of 379 mm spread over six months (May–October). Such differences may be expected to affect the magnitude of the erosion and leaching rate at different sites (Jones and Wild, 1975).

**Solar Radiation, Sunshine, Light and Cloudiness**

Solar radiation is the ultimate source of terrestrial and atmospheric energy, and thus merits a prominent position in climatological studies. Solar radiation is very important in agriculture as it is the source of energy used by plants in photosynthesis. Its variation during the seasons gives rise to differences in temperature, pressure, ocean currents, air masses, and other major synoptic phenomena.

The amount of solar energy received at the earth's surface each day depends upon the intensity of the radiation, which varies with the sun's elevation, the amount of cloud cover and the length of day. The length of day itself varies with latitude and with the season of the year. On a yearly basis, Africa receives a very high radiation load (Landsberg et al., 1963). The mean annual incoming (global) radiation in Africa varies from 140 to 220 kcal/cm². In western Africa, the annual incoming radiation is highest in the north at 180–90 kcal/cm² and decreases southwards to about 140 kcal/cm² (Cochene and Franquin, 1967). The lowest daily values occur in periods of greatest cloudiness (generally in August) and also in the winter months because of the lower inclination of the sun (Davies, 1966). It has also been shown by Davies that at Kano (Nigeria) in the cropping period (May–September) daily solar radiation (kcal/cm²) is high, averaging 525, with the highest value of 580 in May and the lowest of 437 in August. Further south at Ilorin (Nigeria) the May and August values are respectively 440 and 455 kcal/cm² per day.

The amount of solar energy received is the chief determinant of dry matter production in plants. Huxley (1965) has reported than an increase of 100 kcal/cm²/day in solar radiation could, at a maximum estimate, increase dry matter production by 22 kg/hectare per day using 1% of the available incoming radiation.

The sunshine hours (roughly from sunrise to sunset) vary with the seasons and latitude. Seasonal variation is greatest at high latitudes and least at the equator. At the equator the day length is always 12 hours, and the maximum variation in day length at the tropics of Cancer and Capricorn is just under three hours either way, i.e. winter days of about 9 hours and summer days of about 15 hours. However, the actual amount of bright sunshine is always much less, owing to the high degree of cloudiness in most parts of the tropics.
Sunshine hours vary from about 1,600 hours per year in the coastal areas of equatorial West Africa to around 4,000 hours in the Sahara, and there is a positive relationship between the yield of a crop and the sunshine hours. A cultivar in which the leaf arrangement is erect can capture maximum sunlight and is expected to give higher yields than one in which the leaf arrangement is spreading and mutually shading.

The duration of light is of major importance to the growth and development of plants. The relative length of the daily light and dark periods (photoperiodism) has a profound influence on such processes as flowering, tuber formation and seed germination. Plants have been classified on the basis of their photoperiodic requirements for floral initiation into long-day (usually more than 14 hours), short-day (less than 10 hours), day-neutral and indeterminate (requiring 12–14 hours). Actually, the duration of the night or of complete darkness is often more important than the length of daylight.

Many temperate crops are reproductively long-day plants, but many tropical crops are apparently insensitive to daylength (for example, groundnuts, cotton, cocoa, some cultivars of rice and some grain legumes), while others flower and form tubers only in response to short or shortening days (for example, some sorghum and bulrush cultivars, some cultivars of rice, sweet potatoes and some grain legumes). Some plants have different photoperiodic requirement for different developmental stages; wheat, for example, is day-neutral for floral initiation, but long-day for grain formation.

**Temperature**

Temperature is closely connected to radiation and elevation. In Africa, with its relatively small annual variation in radiation, there is a small annual range of temperature. About one-third of the continent experiences an annual range of less than 6°C. The least temperature variation (less than 3°C) is found within 6°N and S of the equator; as latitude increases, temperature variation also increases, reaching maximum values in the desert areas near the tropic of Cancer. The widest temperature variation is found in the areas of least rainfall.

In contrast, the continent has large areas in which the diurnal range is great, often exceeding 15°C. In fact, most of the continent has a diurnal range far in excess of the annual range, giving credence to the statement that ‘night is the winter of the tropics’. In some of the highlands, the large diurnal fluctuation leads to a daily freeze-thaw cycle, and the vegetation and soil of such regions show
a distinct relationship with this phenomenon. High temperatures (higher than 32°C) are found over much of the continent. About 30% of the continent experiences values in excess of 38°C; a maximum of 47°C has been recorded in south-west Algeria. Very small areas have temperatures below 5°C and only in Algeria, Morocco and southern Africa, at elevations of about 1,000–1,500 m, do temperatures fall below 0°C.

Each crop has its own approximate temperature range, i.e. its minimum, optimum and maximum temperatures for growth. Although they are subjected to a rather wide range of temperatures, most crops make their best development between 15°C and 32°C. They cease growth or die when the temperature becomes either too low or too high.

Low temperature is not normally a limiting factor to crop growth and production in the tropics, except where the temperature is markedly reduced by altitude. As a general rule, mean annual temperatures decrease by 0.6°C for every 100 m increase in elevation in the tropics. This has a very marked effect on climate and agriculture in the highlands. In Kenya, for example, there is a sharp contrast between the tropical crop production at, or near, sea level and the extensive semi-tropical farming in the highlands above 2,000 m.

Some tropical crops can tolerate higher temperatures than other. Bulrush millet is more drought-resistant than maize. The adverse effects of high temperature are commonly associated with water strain. For example, high temperatures and low humidity may kill maize tassels by desiccation, cause boll shredding in cotton, or premature fruit drop in certain fruit trees.

**Humidity**

Humidity is water vapour in the air. Relative humidity is the vapour pressure in the air in terms of the percentage necessary to saturate the atmosphere at a particular temperature. A saturated atmosphere that causes fog, dew or rain has a theoretical relative humidity of 100%. The lower the relative humidity at a given temperature the more rapidly will the air take up water transpired by the leaves or evaporated from a moist soil surface. Evapotranspiration increases with increase in temperature and decrease in relative humidity.

Atmospheric humidity varies both with the absolute amount and the seasonal distribution of rainfall, being uniformly high throughout the year in wet equatorial and wet seasonal climatic regions, and falling to very low levels in places where there is a severe dry season. There is also usually a marked diurnal variation in humidity. Even in rain forests where the relative humidity
throughout the year is always at or near saturation point during the night, it may fall to as low as 70% during daylight on dry days.

Relative humidity shows very large variations over Nigeria and most of Africa. In the coastal regions, the months of June to October have monthly means of over 90% while in the north, from January to April, mean values are close to 20 or 25%. Relative humidity has a considerable effect on evapotranspiration, and hence on the water requirements of crops. In the arid regions, relative humidity tends to be low, a mere 12–30% being common around midday. Low humidity combined with high temperatures increases the difficulty of maintaining an adequate supply of water to the plants. The occurrence of high humidities over long periods, combined with high temperatures, favours the rapid development and spread of fungus diseases of crops and moulds on stored produce. In some areas, drying out grain to a low enough moisture content to permit storage in good conditions becomes difficult.

Wind
Wind influences plant growth in arid regions which are characterized by frequent and strong winds. Winds can carry dust from the desert for considerable distances to form loess deposits in neighbouring regions.

Wind originates either over the oceans or deserts. In summer, the desert regions become heated; the heated air rises, causing an indraught of winds from neighbouring regions. If these winds pass over an ocean they become moisture laden. These are the monsoon winds. During the winter, the desert areas are cooler than the adjacent areas, and the wind blows from the desert. These winds, called harmattan, are at first relatively cool and dry and become progressively hotter and drier as the spring advances.

Wind affects both the soil and the plant. The heavier sand particles carried by wind cause soil erosion by scouring the soil surface. The effects on plants are both mechanical and physiological. The sand and dust particles carried by the wind damage plant tissues and can destroy seedlings either by completely covering or uprooting them. They also cause considerable losses through lodging, stalk breakage and grain shedding. The physiological effects of wind induce evapotranspiration, affecting the water balance, while hot dry winds adversely affect photosynthesis by causing the stomata to close.

Wind can have some beneficial effects; moderate winds can enhance photosynthesis by continuously replacing the carbon dioxide absorbed by the leaf surface.
THE MAJOR CLIMATIC ZONES OF TROPICAL AFRICA

Wet Equatorial Climates
Wet equatorial climates occur mainly within 5° north and south of the equator, where the climate is dominated for most of the year by deep, moist, equatorial air masses, and heavy convectional rainfall is frequent. The total precipitation usually varies from 2,000 to 3,000 mm per annum, although in some places it may exceed this. In most of these areas there is some rain in all the months of the year, but in some areas there may be periods of two to three months that are distinctly less wet than others.

Another characteristic of this climate is the small variation in incoming solar energy, which leads to relative uniformity in temperature and which also means that the driving force for atmospheric variation is not subject to rapid changes. In this area temperatures show little variation, the monthly mean usually being around 28°C, and mean monthly maxima and minima about 31 and 25°C. Day length varies little from 12 hours all the year round. This type of climate is characterized by constant heat, rainfall and humidity. Rainfall exceeds potential evapotranspiration in all or most months. This type of climate occurs in the great basin of the Congo River and in a narrow interrupted strip along the northern coast of the Gulf of Guinea.

As far as vegetation is concerned, the whole area can be divided into the following two zones.

Hot, wet zone
This zone does not have more than two dry months. In this zone there is the ideal combination of high temperature and sufficient soil moisture for prolific vegetation growth. The annual total rainfall is more than 2,000 mm and in all months there is at least 100 mm rainfall. Temperatures are uniformly high during each month.

The climax vegetation is usually luxuriant evergreen rainforest. Since neither lack of rainfall nor low temperatures limit crop production, there are no marked agricultural seasons. Commercial crops are mainly perennials such as rubber, oil palms, bananas, coffee and, to a lesser extent, coconuts and cocoa. Root crops such as yams and cassava are often the most important subsistence crops. A few cultivars of maize adapted to local conditions are grown.

Hot, short dry spell zone
On the poleward side of the hot, wet zone there is a belt of land where the total annual rainfall is usually less than 2,000 mm and
where there is a relatively dry spell of three to four months, with a monthly rainfall of less than 100 mm. The vegetation generally changes from tropical forest on the equatorial side to deciduous woodlands on the poleward side of the zone.

On the equatorial side of this zone, the climax vegetation is luxuriant evergreen forest. Rubber, oil palms, coffee, cocoa, citrus, yams and cassava are the important crops of this zone. During drier periods rice is also grown.

Seasonal Climates
The regions lying between the wet equatorial climatic zone and the belts of dry tropical climate tend to have an alternation of a wet
season controlled by the Inter-Tropical Convergence Zone (ITCZ, sometimes called Intertropical Front or Equatorial Trough) conditions at a time of high sun (summer), and a dry season controlled by continental tropical air masses at a time of low sun (winter). Such an alternate wet/dry climate is found in vast areas of great agricultural importance lying roughly between 5–12°N and 5–25°S. Vegetation is roughly correlated with latitude. The seasonal pattern can be more or less disrupted by the geographical location of ocean, great lakes and highlands in relation to the equator.

Near the equator the two annual overhead passages of the sun are of relatively short duration and relatively widely spaced in time. Consequently there tend to be two rainy seasons and two intervening dry seasons each year, or at any rate, two periods of peak rainfall and two intervening spells of lower rainfall (Fig 6). Near the tropics the two overhead passages of the sun are slower and closer together in time, so that the two periods of peak rainfall corresponding with these passages tend to coalesce, and there is only one rainy season and one dry season per year.

In general, the seasonal variation in temperature, as well as the length and severity of the dry season tend to be greater as one moves away from the equator. Places farther from the equator have markedly cool periods during the early and mid dry season, with temperatures rising to high peaks just before the rains. On the other
hand, nearer the equator the temperatures do not rise so high just before the rains, nor do they fall so low during the earlier part of the dry season. In spite of seasonal variations, annual precipitation is equal to or lower than annual potential evapotranspiration.

In this region there also large differences from place to place in the total annual rainfall and in the duration of the wet and dry seasons. In western Africa, for example, the rainfall tends to decrease and the length of the dry season to increase as one moves away from the equator (Figs 7, 8; Wrigley, 1971).

As far as vegetation is concerned, the whole region can be divided into three zones.

**Annual rainfall of 1,000–2,000 mm**
There are two rainy seasons with short dry seasons, or months, with lower rainfall (usually less than 50 mm). Because of the favourable rainfall conditions, perennial crops such as coffee, tea and bananas, and in some areas (the southern parts of Nigeria and Ghana), oil palms and cocoa are grown. Maize, pulses, yams and cassava are important annual crops.

**Annual rainfall of 650–1,500 mm**
There are two short rainy seasons separated by a pronounced dry season of a few months with less than 25 mm rainfall. Drought-resistant perennials such as sisal and cashew are grown. In more
favoured highland areas such as the East Rift area of Kenya, coffee is grown at altitudes of 1,750–1,850 m. The main annual crops are maize, sorghum, finger millet, groundnuts, beans, sweet potatoes, cassava and other legumes.

**Annual rainfall of 650–1500 mm**
There is a fairly long rainy season (normally 5–6 months each having more than 75 mm rainfall) and one long dry season. These areas are not usually suited to perennial crops. In some areas of higher rainfall and at high altitudes, tea and coffee are grown. These regions are generally more suitable for annual crops than regions where the rainfall occurs in two short wet seasons. The main annual crops are maize, sorghum, finger millet, groundnuts, beans, sweet potatoes, cassava and other legumes. Yams and cotton, which require a longer or more reliable rainy season, are also grown in this region (Figs 9, 10).

**Dry Tropical Climates**
Along the southern fringe of the Sahara lies a narrow belt of land (stretching from Dakar on the west coast to the Ethiopian Massif) in

![Map of Nigeria showing main ecological zones](image)
which rain falls with some regularity for a short period of the year. The annual rainfall of this region totals 250–650 mm. There is one short rainy season of three to four months, each having more than 50 mm rainfall, and one long dry season. This region experiences a hot desert climate for most of the year and a tropical rainy climate for the rest. In the southern part of the continent, due to the presence of the high plateau, a dry region with such a rainfall pattern and high temperatures (mean of each month greater than 18°C) hardly exists.

During the dry season this zone is very similar to the desert to its north, with large diurnal variations in temperature (except on the narrow coastal strip), high radiation and sunshine, and dust storms during the period from October to April. In the rainy season, cloudy conditions prevail and the zone takes on the hot, humid aspect common to the wet tropics.

Rice is grown along the coastal belt and in the flood plains of the Niger river. In the rest of the area, drought-resistant annuals such as bulrush millet, sorghum, sweet potatoes, groundnuts and sesame can be grown. In some places cotton is also grown, and in south-west Angola, maize, sisal and wheat are grown.

**Tropical Desert Climates**

The annual rainfall of this region totals less than 250 mm. The rainy (or wet) season lasts only a few weeks. There is little rain at any time.
Tropical desert climates are found in the vast area of the Sahara in the north and the Kalahari in the south. The whole area is extremely arid, but not the whole zone is true desert; in some high areas such as the Ahaggar and Tibesti Plateaux, there is enough rainfall to support an open grassland, and a sparse, nomadic population.

The whole of this arid zone is characterized by the general absence of moist air masses. The northern and southern edges of the Sahara show very different annual distributions of their scanty rainfall, the former having winter rains and the latter having summers rains.

Temperatures are normally very high. About half of this zone has recorded temperatures in excess of 45°C and in many places they reach up to 50°C. Minimum temperatures are more a function of the microclimate. Two-thirds of the zone experiences temperatures below 0°C, even in non-mountainous areas. Annual mean evaporation can reach as much as 5 m (or about 14 mm/day) in the central Sahara.

On the northern edge of this area, sorghum, bulrush millet and even cotton are grown where there are irrigation facilities.
3
SOIL AND SOIL FERTILITY

Soils are very complex natural formations which make up the surface of the earth. They are able to provide a suitable environment for plant growth. Six main soil regimes influence the growing conditions of crops: moisture, nutrient, temperature, air, mineral (weatherable) and biological. These regimes are closely related and interdependent.

CLASSIFICATION OF SOILS OF TROPICAL AFRICA

Although there are many systems of soil classification and nomenclature, none is universally accepted. The different systems of soil classification are based on:

* the empirical or taxonomic approach, using properties such as texture, base content, colour, etc.
* the morphological approach, based on profile characteristics as observed in the field
* the genetic approach, using certain formative or environmental factors
* the integrative approach, involving varying combinations of the above approaches.

The empirical and morphological systems are also often combined as the generic approach (Faniran and Areola, 1978).

Although many systems have been developed in different countries, only the following international systems of soil classification are of importance:

* CCTA system (Soil Map of Africa)
* FAO/UNESCO system (Soil Map of the World)
* USA system (Soil Taxonomy)

These are discussed briefly below.

CCTA System

The CCTA system was developed by a Commission for Technical Cooperation in Africa in 1964. The Commission produced the Soil Map of Africa, on which 63 different types of soils are shown.
FAO/UNESCO System
The FAO/UNESCO (1971–78) Soil Map of the World is a compilation of all soil maps available. Soils that are geographically related were combined in 106 soil associations called major soils.

Soil Taxonomy
This system has many features. First is the fact that the primary bases for identifying different classes in the system are the properties of soils as found in the field—properties which can be measured. Second is the nomenclature employed, especially for the broader classification categories. The names give a definite connotation of the major characteristics of the soils in question since Latin or Greek root words are the basis for the names.

Soil Taxonomy classifies a soil in six categories: order, suborder, great group, subgroup, family and series. It has 10 orders, 47 suborders, 225 great groups, and thousands of subgroups, families and series. Sanchez (1976) has reported that out of the 10 orders and 47 suborders, only 7 orders and 11 suborders are found in tropical Africa. Histosols, Mallisols and Spodosols are not found. The following orders and suborders are found in Africa:

* Entisols [Psamments]
* Inceptisols (Aquepts
* Aridisols (Argids, Orthids)
* Alisols (Ustals, Udals)
* Ultisols (Udults, Ustults)
* Oxisols (Orthex, Ustox)
* Vertisols (Usterts).

The seven soil orders that are found in tropical Africa are briefly described below. The description is based mainly on the report of Donahue et al. (1977).

Entisols
Entisols are soils of recent origin and are identified by the absence of distinct pedogenic (naturally developed) horizons. They range from deep sands to stratified river-deposited clays. Entisols include the soils of river flood-plains, the rocky soils of mountainous areas, and beach sand. Some Entisols are excellent agricultural soils (flood-plains, volcanic ash). When adequately fertilized and when their water supply is controlled, some of these soils are quite productive.

Inceptisols
Inceptisols are weakly developed soils, but have more development than Entisols. Like Entisols, they include profiles very different from
one another. Some are poorly drained (Aquerts), some are high in volcanic ash (Andepts), and some may be light-coloured soils with weak B₄ horizons of clay accumulation (Ochrepts). Some Inceptisols are excellent agricultural soils; others are quite poor.

Aridisols
Aridisols, the first soil order whose soils have well-developed pedogenic horizons, have developed under conditions of low soil moisture and have little or no water leaching through the profile. The natural vegetation found on these soils consists of scattered desert shrubs and short grasses. Many Aridisols are among the most productive soils when they are irrigated and fertilized.

Alfisols
Alfisols with good base saturation (more than 35%) have a distinct argillic (clay accumulation layer) B horizon. Humid and subhumid climates, and tall grasses and savanna, characterize the climate and native vegetation of areas where Alfisols occur. Most of them are slightly to moderately acid in the surface horizon. In general, Alfisols are fairly productive.

Ultisols
Ultisols are soils of the humid areas. They are too low (less than 35%) in base saturation (acidic) to be Alfisols, but not weathered enough to be Oxisols. Ultisols usually have their genesis in humid climates and a forest or savanna vegetation. Usually they are well-drained red or yellow soils and of relatively low fertility. Although Ultisols are not naturally as fertile as Alfisols, they respond well to good management.

Oxisols
Of all soils, Oxisols are the most intensely weathered. They have lost much of their silica and are rich in iron and aluminium oxides (sesquioxides) and kaolinitic clays. Usually they are deep, well drained red or yellow soils with excellent granular structure but very low in fertility. Oxisols are very low in nutrients. Most of them are either still covered with native vegetation or have been tilled by primitive methods. Oxisols may be highly productive for carbohydrate and oil crops but are less productive of protein foods.

Vertisols
Vertisols are heavy, often dark, clay soils. They have a high content of swelling-type clays (more than 30%, mostly montmorillonite). They expand and contract more than any other soil because of the
high clay content, making cultivation difficult. When dry, they develop wide, deep cracks more than 1 cm wide to a depth of 50 cm. They are sticky and plastic when wet and hard when dry. Since they dry out fairly rapidly, the period available for ploughing is very short and this is a limiting factor with these soils. In spite of their limitations, these soils are widely cultivated to sorghum, millet and cotton.

SOIL FERTILITY AND PHYSICAL FACTORS
Soil fertility is the ability of the soil to produce high yields consistently, provided environmental factors such as light, temperature, moisture, etc. are not limiting and crop management practices are efficient.

The soil is a complex medium in which physical, chemical and biological activities are continuously proceeding and interacting. These activities influence the soil to a great extent. The physical properties of a soil largely determine the way in which it can be used most effectively. The physical properties are those responsible for the transport of air, heat, water and solutes through the soil. Those that influence soil fertility are:

* rooting depth
* texture
* structure
* porosity
* bulk density
* temperature
* air
* moisture.

Rooting Depth
Insufficient soil depth for adequate root development is the most obvious physical property that can affect crop yields. There is a positive linear relationship between the effective rooting depth and yield of a crop. Soil properties which prevent roots from penetrating the subsoil are hard pans, platy structure, stratified layers, etc.

Texture
Soils are comprised of mineral particles of varying sizes. The International Society of Soil Science divides these particles into coarse sand (2.0–0.2 mm), fine sand (0.2–0.02 mm), silt (0.02–0.002 mm) and clay (<0.002 mm). The textural names sandy, silt and clay are given to soils based upon the relative proportions of each of the three separates, i.e. sand, silt and clay. Likewise, based on the
combinations of the three separates in various proportions, the soils are known as loam, clay loam, sandy loam, silt loam, silty clay loam, etc.

Texture is an important soil characteristic because it affects the infiltration and retention of water, soil aeration, the adsorption of nutrients, microbial activities, tillage and irrigation. A sandy soil is easy to till but has little inherent fertility and easily loses plant nutrients with rapidly drained water. A clay soil has a high potential fertility, considerable ability to retain water and nutrients, but it becomes very hard when dry, and sticky and poorly aerated when wet, and so difficult to till. The ideal soils are those in which particles of the various soil separates occur together in desirable proportions.

**Structure**

Structure refers to the arrangement, size and stability of soil aggregates (or peds). The development of soil structure involves two
processes, the cementing of soil particles to form aggregates and the shaping of the aggregates. The following types of soil structure, based on the shape and arrangement of the aggregates, are found (Fig. 11; Donahue et al., 1977):

* platy: the aggregates exhibit a matted, flattened or compressed appearance
* prismatic and columnar: the aggregates exhibit a long vertical axis and are bounded by flattened sides. Prismatic aggregates have flattened tops and bottoms; the tops of columnar aggregates are rounded.
* angular blocky and subangular blocky: the aggregates resemble imperfect cubes with angular blocky having sharp edges and subangular blocky having fairly rounded edges
* granular and crumb: the aggregates are imperfect spheres, usually about sand-sized. Granular aggregates are less porous than crumb pedds.

Soil structure, together with texture and organic matter content, is responsible for the water-holding properties and aeration of soils. Granular soils have a rapid infiltration rate, blocky and prismatic soils have a moderate rate, and platy soils have a slow infiltration rate.

A soil is said to be of good structure when the air and water move through it at the desired rate. Good structure for growing wet rice is that attained by puddling (i.e. the destruction of aggregates) to eliminate downward water movement. For other tropical crops, good structure is that which maintains aggregate stability upon abrupt changes of moisture and intense rainfall. In the tropics severe desiccation and high temperatures at the soil surface may be followed by abrupt changes due to high-intensity rainstorms.

Excessive tillage causes the excessive breakdown of aggregates into smaller ones. These smaller aggregates (less than 1 mm in diameter) restrict air movement and cause severe soil crusting after each rain or irrigation. Smaller-sized aggregates are more desirable for rain-fed agriculture because of their better water-holding capacity, whereas larger-sized aggregates are favourable for irrigated agriculture, as they drain easily and ensure better aeration of the soil. Soils with a stable structure are more resistant to wind and water erosion.

Cultivation can also destroy structure by pulverizing the soil when it is dry, and by puddling, smearing and compacting it when it is too wet. In traditional tillage with hoes and light animal-drawn implements, these effects are not serious on most soils.

In most parts of Africa, forest clearing is a common feature. The
clearing of a forest soil leads to a deterioration in stability, causing soil compaction problems. Intensive rainfall accompanied by a rapid decrease in organic matter content accelerates compaction. The maintenance of soil structure is assisted by providing a protective cover of crop vegetation or mulch and by constant intercropping to prevent soil compaction. Under traditional systems where the cultivation of a crop is followed by fallowing, the physical condition of the soil deteriorates during the cropping period and is partially restored during the fallow period.

Porosity
Soil pore space is the volume occupied by air and water. As soil particles vary in size and shape, so pore spaces also vary in size, shape and direction. Sands have large and continuous pores; clays have very small pores. The ideal fertile soil will have sufficient pore spaces, more or less equally divided between large and small pores. The larger pores ensure the free movement of air, and the smaller ones good water-infiltration and holding capacity. The physical condition of a soil that is favourable for root growth depends on the size and distribution of the pores, which determine its permeability to rainfall and roots, as well as the water and air content.

Bulk Density
Bulk density is a measure of pore space in the soil. As a rule, the higher the bulk density, the more compact the soil, the more poorly formed the structure, and the smaller the amount of pore space. This is quite frequently reflected in restricted plant growth. High bulk density may inhibit the emergence of seedlings and may offer increased mechanical resistance to root penetration.

Temperature
Soil temperature is seldom considered a serious limiting factor in the tropics, because soil temperatures approximate air temperatures to a depth of about 50 cm, which is usually adequate for most tropical crops. However, there are two instances in which soil temperatures can be limiting: very high temperatures in certain sandy topsoils, and cool temperatures in the tropical highlands.

Most of the soils of West Africa contain high sand and gravel levels, and retain much heat, particularly when dry. High temperatures in top soil (42°C at 5 cm depth and 38°C at 10 cm depth) at Ibadan (Nigeria) were found to inhibit the emergence and growth of yams, maize and soybeans; and also to affect nutrient and water uptake (Lal et al., 1975). These effects can be minimized by
mulching with straw and stover from a previous crop. Top soil temperature decreases as crops grow and a canopy is established.

In the tropical highlands, crops suffer from low temperatures. Low soil temperature exerts a negative influence on nutrient uptake. This negative effect can be reduced by mulching or by covering the soil with plastic or transparent polyethylene.

Air
The air content of soil ranges from 5–40% of the pore space. For the diffusion of oxygen into, and carbon dioxide out of, the root zone, it is necessary to have a continuous system of pores containing air, extending from the soil surface throughout the root zone. Soil air usually contains sufficient oxygen for the vital processes of the plant and the soil microbes. In soil with poor structure or those which are excessively wet, there is a short supply of air.

The carbon dioxide content of soil air is not constant. The addition of organic matter to the soil usually results in a rapid increase in CO₂ and a corresponding decrease in soil oxygen. Oxygen deficiency and excessive CO₂ in the root zone have a depressive effect on the growth of most crop plants and their associated microorganisms.

Under waterlogged conditions, the diffusion of O₂ into, and CO₂ out of, the soil ceases. As a result, root development slows down and may even stop. Certain crops such as rice are capable of growing normally in waterlogged conditions. In these crops O₂ is absorbed by the aerial parts of the plant and transported to roots through the continuous intercellular spaces in the stems and roots.

Moisture
Moisture is essential for plant growth; growth is restricted at very low and very high levels of moisture. Soil moisture and organic matter content determine the amount of water soils can hold. The increased content of clay and organic matter in the soil increases total water retention. They also cause a large amount of water to be tightly held close to the surface by adhesion. In less clayey soils with less surface area or in soils with less organic matter, more of the total water is held less strongly. Medium-textured soils such as loams can hold a large amount of available water.

The soil moisture level has a pronounced positive effect on the uptake of plant nutrients. An improvement in nutrient uptake increases the water-use efficiency of plants. Water-use efficiency is the amount of dry matter than can be produced from a given quantity of water.
Crop responses to fertilizers are related to soil moisture. In arid regions where irrigation is practised and the moisture supply is assured, there is little uncertainty about responses to fertilizer applications.

Soil moisture also influences plant growth indirectly by its effect on the behaviour of soil micro-organisms. At extremely low or extremely high moisture levels, the activity of nitrifying organisms is inhibited, with the result that plants may have a reduced supply of available nitrogen at their disposal.

SOIL FERTILITY AND CHEMICAL FACTORS

The chemical properties of a soil affect mineral solubility and nutrient availability to crop plants. Properties that influence soil fertility are:

* soil colloids
* soil reaction (pH)
* plant nutrients
* organic matter
* buffering capacity.

Soil Colloids

The most active portions of the soil are those in colloidal state. The colloidal state refers to a two-phase system in which one material (or materials) in a very finely divided state is dispersed through a second. When a soil sample is stirred in water, the smallest particles remain in suspension. These are the soil colloids. There are two distinct types of colloidal matter, inorganic and organic, which exist in intimate intermixture. The inorganic is present almost exclusively as clay minerals of various kinds and the organic is represented by humus.

**Inorganic clay colloids**

Two groups of clays are found, the silicate clays mostly in temperate regions and the iron and aluminium hydrous oxide clays mostly in the tropics and subtropics. All silicate clay particles, because of their small size, expose a large amount of external surface. These minute colloid particles, being anion, ordinarily carry negative charges. Thousands of positively charged ions or cations are attracted to each colloidal particle. Thus a clay particle is accompanied by an enormous number of adsorbed cations. These cations also hold a large number of water molecules. Among the cations that are adsorbed, H, Al, Ca, Mg, K and Na are prominent under natural conditions. Under certain conditions, some clay minerals also exhibit positive charges. This makes possible anion exchange
between surface hydroxyl units and anions such as phosphate, sulphate, chloride and nitrate.

Hydrous oxide clay particles may carry negative charges and attract cations but because of the much smaller number of negative charges per colloidal particle, cation absorption is much lower than for silicate particles. Most hydrous oxides are also not as sticky, plastic, and adhesive as are the silicates. This accounts for the much better physical condition of soils dominated by hydrous oxides. The red and yellow soils of the tropics and subtropics are controlled to a large degree by iron and aluminium hydrous oxides of various types.

**Organic colloids (humus)**
Like the clay colloids, humus colloids are also surrounded by a swarm of adsorbed cations. There are, however, some differences between clay and humus colloids. Humus colloids are basically composed of carbon, hydrogen and oxygen rather than aluminium, silicon and oxygen, as are the silicate clays. Humus is not as stable as clay and is thus somewhat more dynamic, being formed and destroyed much more rapidly than clay.

Regardless of their composition, all colloidal particles are made up of a complex negative radicle of absorbed cations, viz., Al, Ca, Mg, K and Na. These are not all held with equal tightness by soil colloids. The order of strength of adsorption is Al>Ca>Mg>K>Na. Thus in exchangeable form, Al and Ca are the most dominant and Na the least dominant cation. This is generally the case in most well-drained, moderately acid soils of the humid regions.

When organic matter decomposes, organic and other acids are generated. These supply hydrogen which keeps in solution aluminium ions which are quickly adsorbed by the colloids. Aluminium and hydrogen ions are very important because they characterize soil acidity and determine the amount of lime needed for optimum plant growth. Their presence is favoured by high rainfall levels, which tend to leach out the other ions, most of which are held with relatively less tenacity. In arid and semi-arid regions, Ca and other bases do not leach from the soil. These metallic cations therefore tend to dominate the absorptive site and pH values of 7.0 and above result. Under these conditions the Al ions form insoluble compounds and the adsorbed hydrogen ions are replaced by metallic cations.

Exchangeable cations are generally available to both plants and micro-organisms. By cation exchange, hydrogen ions from the root hairs and soil micro-organisms replace nutrient cations from the exchange complex. They are forced into the soil solution, where they
can be assimilated by the absorptive surfaces of roots and microorganisms, or they may be removed by drainage water. Several factors operate to expedite or retard the release of nutrients to plants. The first factor is the proportion of the cation exchange capacity of soil occupied by the nutrient cation in question. The second is the effect of the ions held in association with the given cation. For example, potassium availability to plants has been shown to be limited by excessive quantities of exchangeable calcium. Likewise, in some cases high exchangeable potassium contents have depressed the availability of magnesium (Brady, 1974).

**Soil Reaction (pH)**

Soil reaction (pH) is an indication of the acidity or alkalinity of the soil and is measured in pH units. The entire pH scale ranges from 0 to 14, with pH 7 as the neutral point. Soils under field conditions vary between pH 3.6 and 9.0. At pH 7, the hydrogen ion concentration (H\(^+\)) equals the hydroxyl ion concentration (OH\(^-\)). From pH 7 to 0 the soil is increasingly acidic and from pH 7 to 14 the soil is increasingly alkaline.

The nature of the cations that predominate in the colloidal complex of the soil determines the soil pH; if H\(^+\) is present in considerable amounts in the complex, the soil will be acidic; if Ca or Mg predominate, the soils will be neutral; and if Na and K predominate, the soil will be alkaline.

Besides indicating the acidity or alkalinity of soils, soil pH has a great effect on the solubility of minerals. Strongly acid soils (pH 4.0–5.0) usually have high and toxic concentrations of soluble aluminium and manganese. The major effect of an alkaline pH is to reduce the solubility of all micronutrients (except molybdenum), especially those of iron, zinc and manganese, and also phosphate is often not readily available to some plants. When ammoniacal forms of nitrogen are applied to the surface of soils with a pH greater than 7.0, ammonia is lost by volatilization and the expected responses to the nitrogen applied will not be obtained.

In regions of high rainfall, soils, even from alkaline parent materials, become acidic by the leaching away of the basic cations (Ca\(^++\), Mg\(^++\), K\(^+\), Na\(^+\)) by rainwater and the replacement of many of them by H\(^+\). In regions of low rainfall, excessive acidity rarely occurs and most of the soils in arid regions are alkaline.

The soil pH also influences plant growth by affecting the activity of beneficial micro-organisms. Most nitrogen-fixing bacteria are not very active in strongly acid soils. Bacteria that decompose soil organic matter and thus release nitrogen and other nutrients for
plant use are also hindered by strong acidity. In general, most plants
are best suited to pH 5.5 on organic soils and to pH 6.5 on mineral
soils.

**Plant Nutrients**
These are discussed in more detail in Chapter 5. The organic matter
content of a soil is the storehouse of the mineral nutrients. The
decomposition of organic matter by micro-organisms makes these
nutrient ions available for absorption by plants. Organic matter
holds more than 95% of soil nitrogen, from 5–60% of the total soil
phosphorus and as much as 80% of the soil sulphur.

The total amount of any nutrient in the soil is not an indication of
the amount which is immediately available to a crop, but constitutes
a reserve from which it may become available to plants. The rate of
availability may not necessarily be commensurate with the require-
ments of any actively growing crop. For maximum production, crop
plants require greater amounts of nutrients than the soil solution
contains at any given time.

**Organic Matter**
Organic matter is an active and important portion of a soil. The
organic matter content of a soil is an indication of its fertility.
Organic matter includes all materials of organic origin present in the
soil, regardless of their origin and state of decomposition. It
includes both fresh and highly decomposed crop residues and
animal excretions, as well as the decomposing bodies of soil flora,
fauna and micro-organisms.

Contrary to the commonly held view that tropical soils have low
organic matter contents because of the high temperatures and
decomposition rates, organic matter contents in tropical soils are
similar to those of the temperate regions. Birch and Friend (1956)
studied 570 top soils (0–30 cm) in East Africa and reported that the
mean content of organic matter was 3.36% and that approximately
half of them contained more than 4% in the top 15 cm.

Although most cultivated soils contain only 1–5% organic matter,
mostly in the top 25 cm of soil, this small amount can modify the
soil's physical properties and strongly affect its chemical and bio-
logical properties. It is responsible for desirable soil structure,
increases soil porosity, improves the water infiltration rate and
aeration, is a source of plant nutrients, and reduces soil erosion by
both wind and water. It increases the availability of nutrients
already present in the soil. The large quantity of CO₂ evolved during
the decomposition of organic matter is thought to be important to
the release of certain nutrients, especially inorganic phosphorus.
During decomposition, the released CO₂ dissolves in water and forms carbonic acid resulting in a decrease in soil pH. This effect is of greater importance in neutral and alkaline soils. Under such conditions, the temporary reduction in pH would increase the rate of release of other elements such as boron, zinc, manganese and iron, as well as phosphorus.

In a normal and productive soil, organic matter stimulates the activity of micro-organisms, mainly bacteria and fungi, which decompose the organic matter first into intermediate products (the humic compounds) and finally into simple inorganic compounds such as carbon dioxide, nitrate and water.

To maintain organic matter in soils, all residues that are available should be left on (or in) the soil, and vegetation should not be burnt. Selective crop rotation and minimum tillage can also help maintain adequate organic matter in the soil. One economical way to get more organic matter into the soil is to grow more organic matter by growing larger crops on the farm. Larger crops will mean more roots, more stalks and stubble, more food for livestock and hence more manure to return to the soil.

**Buffering Capacity**

When large amounts of acidic or basic material such as an acidic or alkaline fertilizer are added, most soils can resist large pH changes. This ability to resist a change in pH is the buffering capacity of the soil. The buffering capacity increases as the cation exchange capacity (CEC) increases.

**SOIL FERTILITY AND BIOTIC FACTORS**

The soil surface and top few centimetres of soil teem with microflora and microfauna (commonly referred to as microbes or micro-organisms). Soil microbes and macrofauna may be beneficial, neutral or harmful. Fortunately, beneficial organisms far exceed the harmful ones in number.

Macrofauna include burrowing animals, such as moles, rats and rabbits; earthworms; anthropods, such as mites, millipedes, insects, ants and termites; and gastropods, such as slugs and snails. Microfauna include protozoa and nematodes, and microflora include bacteria, fungi, actinomycetes and algae.

**Functions of Soil Micro-organisms**

**Microfauna**

Protozoa feed mainly on bacteria. This digestion of bacteria influences microbiological populations and hastens the recycling of plant nutrients.
Nematodes are grouped into three according to their different feeding habits. Omniverous nematodes live mainly on decaying organic matter and are the most common of the soil nematodes. Predaceous nematodes prey on soil fauna, including other nematodes, and parasitic nematodes infest plant roots and cause damage to vegetation.

**Microflora**

Bacteria can be divided into two broad categories, based on nutritive patterns. Autotrophic bacteria manufacture food by the synthesis of inorganic materials and heterotrophic bacteria derive food from organic substances. Specific groups of autotrophic bacteria oxidize mineral forms, which are often less useful to plants (nitrites, sulfides) to useful forms (nitrates, sulphates). Probably the most important group of autotrophic soil bacteria are the nitrifying bacteria (*Nitrosomonas* and *Nitrobacter*) that oxidize ammonia to nitrites and then to nitrates. Heterotrophic bacteria include both nitrogen-fixing and non-nitrogen-fixing kinds. The nitrogen-fixing groups are subdivided into symbiotic and non-symbiotic bacteria. The symbiotic bacteria are most commonly associated with leguminous plants, but some are also associated with non-leguminous plants. The non-nitrogen-fixing bacteria are the bacteria most responsible for the decomposition of organic matter. During decomposition, plant residues are broken down and nutrients held in these residues are released for use by plants. Nitrogen is an important example.

Fungi are classified according to their nutritive processes and are parasitic, saprophytic and symbiotic. Parasitic fungi cause plant diseases. Saprophytic fungi live on the roots of certain plants. Fungi help in decomposing organic matter, particularly the resistant parts such as cellulose, lignins and gums.

**Actinomycetes** help in decomposing organic matter, especially cellulose and other resistant forms.

**Blue-green algae** have the ability to fix atmospheric nitrogen. The best soil pH for this fixation is between 7.0 and 8.5. In flooded rice fields, this group of algae helps to maintain the nitrogen level of soil by utilizing atmospheric nitrogen.

**The decomposition of organic matter**

Broadly speaking, soil organic matter can be placed in two categories. The first is a relatively stable material termed humus which is somewhat resistant to further rapid decomposition. The second includes those organic materials that are subject to fairly rapid decomposition.
Although all the same nutrients and environmental conditions needed by plants seem to be needed by the heterotrophic soil microbes that decompose organic matter, nitrogen is the nutrient whose concentration most often controls the rate of organic matter decomposition. This is because nitrogen is needed to permit the rapid growth of the microbial population which accompanies the addition to the soil of a large supply of carbonaceous material.

The ratio of the percentage of carbon to that of nitrogen is termed the carbon nitrogen (C:N) ratio. The C:N ratio of stable soil organic matter is about 10:1. As a general rule, when organic materials with a C:N ratio of greater than 30 are added to the soil, there is immobilization (conversion of inorganic or mineral nitrogen to the organic form) of soil nitrogen during the initial decomposition process. For ratios between 20 and 30 there may be neither immobilization nor mineralization (conversion of organic nitrogen to a mineral form, viz. $\text{NH}_3^+$, $\text{NO}_2^-$, $\text{NO}_3^-$). If the organic materials have a C:N ratio of less than 20, there is usually a release of mineral nitrogen (mineralization) early in the decomposition process. There are, however, many factors other than the C:N ratio which influence the decomposition of organic materials and the release or immobilization of nitrogen.

The mineralization of organic nitrogen compounds takes place in essentially three step-by-step reactions: aminization, ammonification and nitrification. The first two are effected through the medium of heterotrophic microbes and the third is brought about by autotrophic bacteria.

Aminization is the process in which organic matter is decomposed by enzyme digestion by numerous groups of heterotrophic bacteria and fungi, releasing amines and amino acids. It can be represented as follows:

$$\text{organic matter + enzymic digestion} \rightarrow R-\text{NH}_2 \ (\text{complex amino compounds}) + \text{CO}_2 + \text{energy} + \text{other products}$$

Ammonification is the step in which the amines and amino acids so released are further utilized by other groups of heterotrophic microbes with the release of ammoniacal compounds. It may be represented as follows:

$$R-\text{NH}_2 + \text{HOH} \xrightarrow{\text{ammonification}} R-\text{OH} + \text{NH}_3 + \text{energy}$$

$$2\text{NH}_3 + \text{H}_2\text{CO}_3 \rightarrow (\text{NH}_4)_2\text{CO}_3 + 2\text{NH}_4^+ + \text{CO}_3^-$$

Nitrification is a two-step process in which some of the released $\text{NH}_4^+$ is first converted to nitrile ($\text{NO}_2^-$), a toxic form of nitrogen that is short-lived and then to nitrate ($\text{NO}_3^-$). The first step in the conversion is brought about largely by a group of obligate autotrophic
bacteria known as *Nitrosomonas* and the second step largely by a second group of obligate autotrophic bacteria known as *Nitrobacter*. The two steps can be represented as follows:

\[ 2\text{NH}_4^+ + 3\text{O}_2 \rightarrow 2\text{NO}_2^- + 2\text{H}_2\text{O} + 4\text{H}^+ + \text{energy} \]
\[ 2\text{NO}_2^- + \text{O}_2 \rightarrow 2\text{NO}_3^- + \text{energy} \]

**Denitrification**

Soil nitrogen can be lost in ways other than leaching and crop removal. These losses occur when nitrogen gas is released because of denitrification and ammonia volatilization. The most extensive loss is by denitrification brought about by bacteria converting nitrate to nitrogen gas or its oxide (mostly N\(_2\) and N\(_2\)O). It usually occurs when poor aeration limits the amount of free oxygen in the soil; bacteria are then forced to use the oxygen in the nitrate ions (NO\(_3^-\)) for their needs, leaving the nitrogen (N\(_2\)) and nitrous oxide (N\(_2\)O\(^-\)) residues to volatalize and so move from the soil into the atmosphere.

In waterlogged soils, anaerobic decomposition takes place through species of the genera *Pseudomonas*, *Micrococcus* and *Bacillus*.

**Nitrogen fixation**

Nitrogen fixation is the assimilation of free nitrogen from the air by soil organisms and the synthesis of nitrogen compounds that eventually become available to plants. These processes are carried out by several kinds of soil microbes. Nitrogen fixation is carried out by *Rhizobia* and other microbes which live symbiotically in the roots of legumes and certain non-leguminous plants, and by free-living micro-organisms (non-symbiotic). The symbiotic fixation of nitrogen by legume bacteria can add 50–280 kg/ha per year of nitrogen, whereas nitrogen fixed by non-symbiotic micro-organisms varies from a few kg/ha to 112 kg/ha per year (Donahue *et al.*, 1977).

**Symbiotic nitrogen fixation**: the roots of leguminous plants excrete a substance which attracts the bacteria and promotes their rapid multiplication. The bacteria produce a growth substance that enables them to penetrate into the roots through the root hairs. They multiply rapidly and cause swellings, called nodules, on the root.

The nitrogenous substances formed by the bacteria are partly absorbed by the bacteria to build body protein, partly by the host legume plants, and partly excreted into the soil where they may benefit non-leguminous plants growing in association with the legumes. Since the life-span of a single bacterium is only a few hours, the bodies of a portion of the bacteria population are continuously dying, decomposing and releasing ammonium (NH\(_4^+\)) and
nitrate (NO$_3^-$) ions for use by the host plant and other plants growing in association.

Nitrogen fixation is at a maximum when the level of available soil nitrogen is at a minimum. It is generally advisable to apply a small amount of nitrogen to the legumes at planting time to ensure that the young seedlings will have an adequate supply until the *Rhizobia* can become established on their roots. Large and continued application of nitrogen, however, reduces the activity of *Rhizobia* and is therefore generally uneconomic.

**Non-symbiotic nitrogen fixation:** nitrogen fixation in soil is also brought about by certain free-living organisms which exist independently in soil and in water, convert nitrogen into body tissue nitrogen forms and then release it for plant use when they die and decompose. These organisms include numerous species of the blue-green algae and free-living bacteria. The most important of these bacteria are *Rhodospirillum*, which is photosynthetic, *Clostridium*, which is an anaerobic saprophyte, and *Azotobacter*, an aerobic saprophyte.

Certain blue-green algae have the ability to fix atmospheric nitrogen. This group of algae fixes atmospheric nitrogen in flooded rice fields but is also considered to be capable of adding appreciable amounts of nitrogen to the soils of arid regions.
SOIL EROSION AND CONSERVATION

SOIL EROSION
The adoption of suitable measures for the conservation of soil and water is very important in areas where soil erosion is a problem. Soil erosion is a natural and world-wide phenomenon. The removal of the fine-grained material of soil, especially of the top soil, by water and wind and their deposition where the movement of water and wind ceases, is a natural phenomenon. In nature, the process is so slow and continuous that an equilibrium is normally established between the slow process of soil formation and the removal of soil by erosion. Problems arise when man starts disturbing this equilibrium by clearing forests, removing vegetation, adopting faulty techniques of cultivation and undertaking construction works. All these expose the soil to the battering effect of raindrops which break down the soil aggregates and seal the surface so that the percolation of rainwater is diminished and run-off is correspondingly increased.

The indigenous systems of farming developed in tropical Africa, where heavy to very heavy rainstorms are characteristic of the climate, are usually conservative, and result in little soil erosion. The traditionally adopted systems of shifting cultivation are well suited to the control of soil erosion and the maintenance of soil fertility for annual crops. However, these systems are only well adapted to low population densities, and require an extensive use of land. In the early days, when shifting cultivation was very common, there was a balance between the human population and soil fertility and therefore soil erosion was restricted. Increasing population densities are increasing the proportion of land under cultivation either by shortening the time the land is under fallow, or by cultivating land that is traditionally considered unsuitable for cultivation. This has resulted in a serious soil erosion problem.
Erosion causes not only the loss of top soil, but also a reduction in the fertility of the soil, resulting in lower crop yields. Erosion not only reduces yields on sloping land but may also seriously lower the productivity of the flat lands below as a result of floods depositing large quantities of coarse sand, gravel or stones, which bury the surface soil of the lower land.

Erosion is often accompanied by a marked deterioration in water supply. Where a large proportion of the rainfall is dissipated as run-off, instead of percolating through the soil to feed springs and subsurface aquifers, streams cease to flow for part of the year and wells dry up, so that lower areas at some distance from the site of erosion may be deprived of their water supply. This may be serious in areas of relatively low rainfall because, as erosion and run-off increase, a progressive process of desiccation sets in. Streams and wells are dry for long periods and the water table is lowered. For want of water the vegetation becomes sparser or changes its character, and semi-desert conditions are eventually reached.

The effects of soil erosion are not confined to the site where it has occurred but apply to a wide area. The reduced permeability of the newly exposed soil causes a reduction in water retention and an increase in the amount of water running off the surface. This ultimately leads to floods, changes in the depth of river beds, the erosion of streams and river banks, and related effects. The transport of soil particles in the run-off water leads to problems where the water stops moving and the silt is deposited. This may be the burial of crops or of more fertile topsoil. It also leads to a reduction in the permeability of the soil where the silt is deposited, as the fine particles settle in the water-conducting pores of the soil profile.

The elements causing soil erosion are mainly determined by the climate. In the forest zone of the tropics the main causative agent is rain, while in the dry savanna it is wind. In the moist savanna, both agents are at work.

**Erosion Caused by Water**

Soil erosion due to water arises when all rainfall does not penetrate the soil, and the excess runs off the surface, carrying with it detached soil particles. The detached material is usually the topsoil, which is rich in plant nutrients. The consequent exposure of subsoil often leads to a lower rate of water percolation, increased run-off and further soil loss, and a continuing cycle of soil deterioration develops.
Kinds of water erosion
The following kinds of water erosion are common:
- sheet erosion
- rill erosion
- gully erosion
- stream bank erosion.

Sheet erosion is the initial stage of water erosion. It takes place in such a natural way that it often goes unnoticed, and the cultivation of land is not hampered by this type of erosion. It is the more or less uniform removal of top soil particles by the even flow of a thin sheet of water. It is a very wide-spread type of erosion which results from a very modest amount of run-off on quite gentle slopes. Sheet erosion is produced by the beating action of large raindrops on the loose soil particles of bare and cultivated land.

Rill erosion is the second stage of erosion. When sheet erosion goes unnoticed and precautionary measures are not adopted, small channels soon appear on the surface of gently sloping land. Run-off is then concentrated in these finger-like channels, giving rise to rills. Though these rills do not present any obstruction to implements during cultivation, they are more noticeable than sheet erosion.

Gully erosion starts when the volume and velocity of the water becomes sufficient to deepen and widen these rills. Gullies may also develop from depressions or channels resulting from up- and downhill ploughing, wheel ruts, cattle tracks or footpaths. Gullies may vary in width and in depth from a few centimetres to many metres (Fig 11b). They obstruct agricultural implements and as a result cultivation is almost always abandoned near gullies. When the water begins to deepen a gully, a small waterfall is formed at its upper extremity and the increased water velocity leads to head erosion, causing the gully to gradually eat its way up the slope to the top of the watershed. The deepening of the gully bed also leads to the undercutting and caving in of the banks, and as the material which falls is rapidly washed away, vertical banks are left to be undercut by the next floods. Once started, gullies may become greatly enlarged in a very short time and it is extremely difficult to check their spread.

Stream bank erosion is mainly the undermining and collapse of banks due to the scour of river flow. It also includes damage from surface run-off over the edges of the banks. The latter is of considerable importance along the banks of smaller streams and is particularly liable to occur where cultivation is done right up to the edge of a water course.
Factors affecting water erosion

The following are the important factors that affect the degree of erosion:

* erosivity (amount, distribution and intensity of rainfall)
* erodibility (detachability and transportability of soil)
* land form (length, magnitude and shape of slopes)
* management (land and crop management).

Erosivity refers to the aggressiveness of the climate. Tropical rains, because of their high intensity, are more erosive than temperate rains. Tropical storms are generally accompanied by high-intensity winds which further increase their aggressiveness.

Erosivity is closely related to intensity of rainfall. The higher the rainfall intensity the greater will be the volume of run-off water per
unit time, and the higher the velocity of the run-off. With high intensity rainfall, the impact of the raindrops causes greater destruction of the soil aggregates and increased sealing of the surface, causing a more erosive run-off. Hudson (1963) found that the rainfall intensity of about 25 mm/hour was a threshold value, higher intensity than this being erosive. Kowal (1970a,b) reported that run-off occurred only when rainfall was greater than 20 mm/hour.

Uniform and well-distributed rain over a longer period allows more water to be infiltrated and supports a good vegetative cover over the land, resulting in less erosion. Erosion becomes serious when the total rainfall falls with high intensity within a short period. Erosion is usually worse in regions with alternating wet and dry seasons than in those with more evenly distributed rainfall, where the soil is nearly always moist and where the vegetation is more continuously maintained. The first rains after a long dry season, as is the case in most of the savanna, are liable to cause much erosion, both on pastures where the herbage has often been greatly reduced by overgrazing and burning, and on arable land, which is exposed after preparatory cultivation.

**Erodibility** is an inherent property of the soil and it refers to the liability of the soil to suffer erosion due to the forces causing the detachment and transport of soil particles. Under similar environmental and management conditions, two different soils sometimes react very differently to erosive forces. This is because of their resistance to erosion and their ability to accept the infiltration of rainfall. Erodibility involves those soil properties that affect infiltration rate and permeability, and the changes with time that occur in these soil properties, as well as other properties that determine the effects of dispersion, splashing, abrasion, and the transporting forces of rainfall and run-off.

The proportion of water reaching the ground surface which infiltrates into the soil depends to a considerable extent upon the relation between rainfall intensity and the infiltration capacity of the soil. As long as the former is less than the latter, all the rain reaching the surface will infiltrate. The infiltration capacity is a variable depending on soil type, condition and moisture content. Both condition and moisture content will vary with time. The impact of raindrops, for example, may lead to the compaction of the soil surface, thereby decreasing the infiltration capacity. With the occurrence of rainfall, soil moisture will be increased, leading to a decrease in infiltration capacity. However, it is not only the soil surface which matters. The characteristics of the lower layers are important since the rate at which water is moved away from the surface layers (permeability) will influence the rate of infiltration at
the surface. The upper layers tend to saturate first before further quantities of water pass to the deeper layers. It will take some time before water penetrates to the latter. Only the surface layer may be moist, resulting in a low infiltration capacity and perhaps surface run-off, while the deeper layers remain dry. Once the upper layers of soil are saturated, downward transport begins and from that time it is no longer the infiltration capacity which dominates, but the permeability.

Various soil properties affect its detachability: texture, structure, porosity, organic matter content, the presence of cementing materials such as Fe and Al oxides, the nature of the clay minerals and the balance of cations on the exchange complex; as well as the properties which are themselves dependent on these, such as permeability and stable aggregation. Fine-textured sandy soils are readily eroded because of their limited and unstable aggregates. Clay loams with stable aggregates are the most resistant types.

Soil transportability depends on both soil and water flow characteristics. For instance, clay-sized particles are more easily transported than fine sand. Less fertile soils are more liable to erosion than a fertile soil. Soil normally loses its good structure and organic matter content under cultivation and as a result the ability to absorb rainfall is gradually reduced. A decline in nutrient status in the soil may indirectly increase erosion by reducing the growth and density of vegetative cover.

Land form also influences the proportion of rainfall moving into the soil. On steep slopes, water will move rapidly over the surface and hence have little time to infiltrate. Both degree and length of slope are important factors in influencing soil erosion. Erosion generally increases with increase in slope. The longer the slope, the greater is the volume and velocity of water, causing greater losses of soil and water, but not in proportion to the degree and length of slope. The degree of slope has a similar effect on soil loss as does length of slope. However, the relation between slope length and erosion is complicated by the shape of the slope, viz. whether it is convex, concave, complex or regular. In the case of an irregular slope, it is the steepest section of the slope which may determine the amount of erosion. Run-off is less severe over a rough surface than over a smooth one. Any obstacles across the slope slow down the rate of flow and give more time for infiltration.

Management is an important human factor affecting erosion. Any sort of canopy either of trees, shrubs, perennial or annual crops, or herbage protects the soil from erosion hazard. The vegetative canopy reduces raindrop impact, improves soil structure by adding organic matter, impedes water movement and acts as a filter through which water is slowly transmitted to the soil. Removal of
this cover in the tropics exposes the soil to direct raindrop impact. The impact stress of these raindrops may be in excess of the strength of most aggregates when wet. Trampling and heavy cultivation implements exert a similar or larger force and lead to a rapid breakdown of surface structure. A deterioration in soil condition is inevitable unless the soil can be protected from these disruptive stresses. Mechanized farming involving the use of heavy machinery on the field will always tend to increase the erosion hazard.

Similarly, overgrazing and indiscriminate burning leave the soil exposed. The excessive trampling of bare soil by livestock also destroys the soil structure with a consequent reduction in infiltration.

The cultivation of annual crops on steep slopes is very dangerous (Fig. 12). This has caused widespread erosion in Africa. Steep land should either be left under forest, or cultivated to certain tree crops such as cocoa. In the absence of suitable conservation measures, soil and water losses under inter-cultivated row crops such as maize or cotton, are usually considerable on sloping land. However, losses can be reduced both by planting at high density in the rows and by mulching. Crops that are drilled in close rows or broadcast, such as wheat, form a reasonably good protective cover.

Erosion Caused by Wind
Whereas water erosion is a problem in heavy rainfall areas, wind erosion is a problem in the arid and semi-arid regions of the tropics.
It also occurs in places with a long dry season, as in the savanna region. However, wind erosion is not as damaging as water erosion. Wind erosion occurs when the surface soil is dry and unprotected by vegetation. It is favoured by a flat or gently undulating topography across which wind can blow unimpeded.

In wind erosion a large mass of soil particles is blown from one area and transported to distant places. On the way, these soil particles destroy the vegetation by their abrasive action. Where these fine soil particles fall, they seal the pore spaces of the soil, thus rendering it more liable to water erosion.

The principal soil feature which affects susceptibility to erosion by wind is the dry aggregate structure and its stability. The coarser-textured soils, lacking in sufficient silt and clay to bind the sand grains into stable aggregates, are very susceptible to wind erosion. Similarly, soils lacking in organic matter content are also susceptible to wind erosion. Tillage methods that pulverize the soil makes it more susceptible to erosion. Ploughing the land during winter or summer, i.e. before the rains, also exposes the soil to wind erosion.

SOIL CONSERVATION

Agronomic Measures to Control Erosion
As discussed earlier, erodibility and erosivity are inherent properties of soil and climate respectively, and little can be done to change them. Erosion control therefore depends on judicious soil and crop management. Soil management practices are based on the following broad principles: those practices which help maintain soil infiltration rates at sufficiently high levels to reduce run-off to a safe amount; and those practices which help the safe disposal of run-off water from the field.

Cultural practices which help maintain a high soil infiltration rate are essentially based on agronomic measures which maintain a mulch or vegetation cover on the soil, such as no-tillage or minimum tillage, stubble mulching, or the use of cover crops.

Tillage
The beneficial effects of tillage, such as increased rainfall infiltration and reduced run-off, are transitory, and frequent land tillage may be harmful. Excessive tillage renders the soil less permeable by breaking down the soil aggregates and it is generally wise to keep cultivation to the minimum required to produce a satisfactory seed bed. Contour cultivation is to be generally recommended as one of the simplest and cheapest conservation measures.
Surface plant residues very effectively control erosion. A very promising planting system gaining popularity is no-till sage planting. One of the means of producing mulch on the soil surface is from crop residues left on the surface when using minimum or no-tillage techniques. The no-tillage system has the further advantage of moisture conservation in the soil profile, in addition to decreasing run-off and reducing soil loss to a minimum. In the no-tillage system the organic matter content of the surface horizon is also better maintained, as is the water holding capacity of the soil. The moisture retention characteristics of the soil are also changed because of no-tillage and the surface soil has higher infiltration rates.

Tied-ridging is another effective practice in controlling erosion. This involves growing crops on ridges made approximately on the contour, adjacent ridges being joined at regular intervals, usually of 1.5–3.5 m by barriers or ties slightly lower than the ridges. The ties are made with soil scraped from the furrow. On gentle slopes with permeable soils of adequate depth in areas not subject to high-intensity rainstorms, the series of basins so formed can hold the rainfall where it falls, allowing it to infiltrate into the soil and preventing all run-off. In such circumstances, ties render ridges that are roughly on the contour effective without the risk of breakage and eliminate the need for other conservation works such as ridge terraces or vegetative barriers.

**Mulching**

Mulching with cut grass or other vegetable refuse (Fig. 13) prevents surface sealing by avoiding direct raindrop impact on the soil, and by encouraging enhanced biological activity which leads to the development of macropores in the soil. It is very effective in reducing run-off and erosion since it protects the ground from the impact of rain, slows down the movement of water over the surface, and improves the permeability of the soil. In Nigeria, mulching was found to be more effective than incorporating crop residues and weeds for reducing run-off and erosion. Its effects increased with the amount of material applied, and the optimum rate is reported as 4,000–5,000 kg/ha (Lal et al., 1975).

Stubble mulching has similar effects to ordinary mulching. In this system, all or part of the crop residues and weeds is left on the surface of the soil as a protective cover. This system involves shallow ploughing of the land after harvest, either leaving the stubble and weeds on the surface or partially burying them. The greater the quantity of stubble and weeds left on a unit of land, the greater the effectiveness of the practice in reducing run-off and soil loss.
Crop rotation and strip cropping

Growing wide-spaced row-tilled crops such as sorghum, maize, cotton, and sugarcane continuously for a few years makes the soil susceptible to erosion. On the other hand, growing grasses or legumes protects the soil from erosion because these provide a complete ground cover while they are growing and also improve the soil structure and permeability. To check or minimize the loss of soil it is therefore advisable to have close-spaced cereal crops such as wheat or finger millet and grasses or legumes, or grass-legume mixtures, in the rotation.

The purpose of strip cropping is the same as that of crop rotation, i.e. to minimize the loss of soil. The difference is that in rotation one has to grow erosion-permitting crops like sorghum, and erosion-reducing crops like grasses or legumes in different seasons, whereas in strip-cropping one can grow these crops in the same season but in different narrow strips on the contours. In strip cropping, strips of erosion-permitting crops are separated by strips of close-growing, protective crops. Thus there may be successive strips of a wide-spaced, row-tilled crop, such as sorghum or maize; a dense untilled crop, such as grasses or legumes and a close-spaced crop receiving little or no cultivation after planting, such as finger millet. In succeeding seasons, these strips are rotated. In strip cropping, no inter-tilled crop strips, or strips having crops of the same sowing and harvesting times, should be adjacent.
**Cover crops**
For effective erosion control, proper land use is imperative. The steepest slopes that are unsuitable for cultivation may be left under forest or permanent pastures; less steep land may be used for highly protective tree crops that provide a full canopy of foliage, such as cocoa; gentler slopes may be planted with less protective tree crops, such as coffee or citrus and the gentlest slopes may be used for arable crops and temporary grass. On each type of land, appropriate soil conservation methods must be employed.

Plantation crops like cocoa, coffee or citrus do not cover the land during their establishment stage, and as they are planted on slopes, it is necessary to cover the land with some quick-growing dense cover crops in the inter-rows (Fig. 14). These crops not only provide a protective cover, but also enhance rainfall infiltration by means of improving the organic matter content of the soil.

**Soil conditioning**
In order to prevent the breakdown of soil aggregates due to raindrop impact, their aggregate stability must be improved. Soil conditioning can provide the soil surface and even the upper soil layer with a more stable structure and with optimal physical properties, minimizing aggregate destruction and helping to preserve a high infiltration capacity.

*Fig. 14  Plant of Centrosema – an important cover crop for soil conservation*
Bitumen emulsion, polyurethane, latex, asphalt, etc. are used as soil conditioners. There are two methods of applying conditioners to the soil, by surface treatment and by incorporation. In surface treatment the conditioner is sprayed at its optimal dilution rate, as a film over the dry soil surface. For incorporation, the conditioner is mixed with the soil at different initial soil moisture contents.

Management
Crop and management practices which help produce an early ground cover are certainly more useful in controlling run-off and erosion than those which take longer for a full canopy cover to develop. Quick-growing crops are termed soil-conserving crops, and slow-growing crops are termed soil-depleting crops. Practices such as mixed cropping also affect ground cover. Soil erosion and run-off losses are proportionally less from mixed crops than from sole crops. Other cultural practices which affect erosion control are plant population, time of planting and fertility level.

Proper soil management practices are more important that the growing habit of a crop. A soil-depleting crop grown with proper soil-conserving techniques such as mulching could cause less run-off and soil loss than a soil-conserving crop grown with erosion-promoting practices. For instance, run-off and soil loss from maize may be less than from cowpea when the former is grown with no-tillage techniques and the latter with conventional methods of ploughing and harrowing.

Most of the above agronomic practices can be adopted to control erosion caused by wind. Measures to control wind erosion aim principally at maintaining more moisture in the soil, increasing surface roughness and reducing wind velocity. To achieve these aims, minimum tillage, ridging at right angles to the direction of the prevailing wind, early sowing, cropping in alternate strips (i.e. in the first year raise a crop in one strip and leave the next strip fallow, and in the next year leave the first strip fallow and crop the second strip), mulching and stubble mulching may be practiced. One of the most effective measures is the planting of windbreaks at intervals across the path of the wind to slow its velocity and to cause the deposition of soil particles already in movement.
5
PLANT NUTRITION

ESSENTIAL NUTRIENTS
For proper plant growth, a regular supply of plant nutrients, especially the essential ones, is necessary. Plants absorb a large number of elements from the soil, air and water during their growth period, but not all of these are essential. Only 16 elements have been found to be essential for all plants and four others have been found to be essential for some plants. The elements which fulfil the following criteria are called essential elements:

* a deficiency of the element makes it impossible for the plant to complete the vegetative or reproductive stage of its life cycle
* the deficiency symptom of the element in question can be prevented or corrected only by supplying that element
* the element must have a direct influence on the plant and must be directly involved in the nutrition of the plant, quite apart from its possible effect in correcting some microbiological or chemical condition in the soil or culture medium.

The essential elements carbon, hydrogen, oxygen, nitrogen, phosphorus and sulphur are the elements of which proteins and hence protoplasm are composed. The other ten elements which are essential for plants are potassium, calcium, magnesium, iron, manganese, molybdenum, copper, boron, zinc and chlorine. The four elements which are essential only for some and not for all plants are sodium, cobalt, vanadium and silicon.

Sources of Nutrients
Carbon, oxygen and hydrogen constitute about 95% or more of the weight of a plant. Plants obtain their carbon and oxygen directly from the air by photosynthesis. The hydrogen is derived from the soil water. Elements other than carbon, hydrogen and oxygen are termed mineral nutrients and are obtained by the plants from the soil. A considerable amount of nitrogen is also fixed by leguminous plants through root nodule bacteria.
Macro- and Micronutrients

Since nitrogen, phosphorus, potassium, calcium and magnesium are utilized in relatively large amounts, they are designated as macronutrients. The first three of the above macronutrients are utilized by plants in considerable quantities and as such they are often called major nutrients. The remaining three, namely calcium, magnesium and sulphur, are sometimes called secondary nutrients due to their secondary importance in plant nutrition. The other nutrients are used by plants in small quantities and are therefore called micronutrients. Other names given to these nutrients are minor, trace or rarer nutrients.

ADDITION OF PLANT NUTRIENTS TO THE SOIL.

Plant nutrients can be supplied to the soil by adding the following fertilizing materials:

* bulky organic manures
* green manures and other crop residues
* concentrated organic manures
* commercial fertilizers
* soil amendments.

Bulky Organic Manures

Farmyard manure, compost, sludge, green manures and other bulky sources of organic matter are known as bulky organic manures. These manures supply plant nutrients in small quantities and organic matter in large quantities. These manures have a direct effect on plant growth, on the humus content of the soil, so improving its physical properties, and on microbial activities in the soil.

Farmyard manure

When animals are kept in a shed and proper care and good management practices are observed in the utilization of all dung, urine and litter for use as farmyard manure, nearly all of the elements originally present in the excreta of the animals can be saved and returned to the soil.

Manure should be prepared in trenches of suitable size, say 10 m long, 2 m wide and 1 m deep. The number of trenches needed depends on the number of livestock kept. Each morning the urine-soaked litter and dung should be well mixed and taken to the manure trench. When the trench is filled to a height of 0.5 m above ground level, the top of the heap is made cone-shaped and plastered over with cowdung-earth slurry. When the first trench is full and covered, a second trench is taken into use. When the manure in the first trench is completely decomposed, it can be emptied and the
trench can again be taken into use. On an average, well-rotted farmyard manure contains 0.5% nitrogen (N), 0.2% phosphorus (P) and 0.5% potassium (K).

**Compost**
Compost is well-rotted vegetable matter which is prepared from farm and town refuse. Farm refuse consists of straw, crop stubble, weeds and crop residues such as groundnut husks, sugarcane refuse, waste fodder, hedge clippings and dried leaves. Town waste consists of sewage, sludge, street and dustbin refuse, factory waste, wool and cotton waste, etc.

Like farmyard manure, compost is also prepared in trenches. These may be of any size, depending on the quantity of refuse to be decomposed. The length, breadth and depth of the trenches may be 10 m, 2 m, and 1 m, respectively. All the available refuse is collected and stored until it forms a sufficient mass to make compost. The accumulated refuse is well mixed and then spread in the trench in a layer of about 0.3 m. This layer is then well moistened by sprinkling over it a slurry of cowdung and water, or earth and water. Subsequent layers of the same thickness of mixed refuse are then spread on the heap and moistened until it has reached a height of about 0.5 m above ground level. The top of the heap is then covered with a thin layer of earth. After decomposing for about three months, the partially decomposed material is taken out of the trench, formed into a conical heap above the ground and covered with earth. After another one or two months, the compost will be ready for use. Compost from town refuse is prepared in more or less the same way as described above.

The N, P and K contents of farm compost are on an average 0.5%, 0.15% and 0.5%, respectively while those of town compost are 1.4%, 1.0% and 1.4%, respectively.

**Green Manures**
Green manuring is the practice of growing and ploughing in green crops to increase the organic matter content of the soil. There is now some doubt as to whether this practice appreciably increases the organic matter content of the soil, and it is a rather unsatisfactory substitute for farmyard manure.

Green manuring is only feasible where an extensive type of crop cultivation is practised or where a farmer is ready to forego a crop to grow a green manure crop. In intensive cultivation, where large amounts of crop stubble, crop refuse and weeds are incorporated in the soil, green manuring may be unnecessary.
A green manure crop (preferably a leguminous one), should be sown at the beginning of the rainy season. The crop should be a quick-growing one and have a leafy habit capable of producing heavy tender growth early in its life cycle. It may be ploughed in at the flowering stage. The majority of green manure crops take about six to eight weeks from time of sowing to attain the flowering stage.

The green manure crop should be completely decomposed before sowing the next crop. The time it takes to do so depends on the weather conditions and the nature of the buried green crop. High rainfall and high temperatures favour rapid decomposition. Similarly, when the buried green manure crop is succulent, less time is needed for its decomposition.

Concentrated Organic Manures
Concentrated organic manures are those that are organic in nature and contain higher percentages of nitrogen, phosphorus and potash than bulky organic manures. Concentrated organic manures are made from raw materials of animal or plant origin. The common concentrated manures are oil cakes, bloodmeal, fish manure, meatmeal, and cotton and wool wastes (shoddy).

Oil cakes
Oil cakes are the material left over after expressing oil from oilseeds. Oil cakes contain N, P, K and a large percentage of organic matter. The nutrient content of some oil cakes are given in Table 2.

<table>
<thead>
<tr>
<th>Name of oil cake</th>
<th>Percentage composition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
</tr>
<tr>
<td>Groundnut</td>
<td>7.3</td>
</tr>
<tr>
<td>Linseed</td>
<td>4.9</td>
</tr>
<tr>
<td>Sesame</td>
<td>6.2</td>
</tr>
<tr>
<td>Caster</td>
<td>4.3</td>
</tr>
<tr>
<td>Rape-mustard</td>
<td>5.2</td>
</tr>
<tr>
<td>Niger</td>
<td>4.7</td>
</tr>
<tr>
<td>Safflower (undecorticated)</td>
<td>4.9</td>
</tr>
<tr>
<td>Safflower (decorticated)</td>
<td>7.9</td>
</tr>
<tr>
<td>Cottonseed (undecorticated)</td>
<td>3.9</td>
</tr>
<tr>
<td>Cottonseed (decorticated)</td>
<td>6.4</td>
</tr>
</tbody>
</table>

Oil cakes are quick-acting organic manures. Their nitrogen becomes available to the plants in about a week after application. They should be well powdered before application, so that they can be spread evenly and be easily decomposed by micro-organisms.
Well powdered oil cakes can be applied even at sowing. They can be broadcast or drilled.

**Commercial Fertilizers**

The rapid increase in population in all the countries of tropical Africa, and the general increase in the standard of living after becoming independent, have greatly raised the demand for food and feed grains. In recognition of this need, most of these countries are adopting an intensive system of agriculture in place of the traditional bush-fallow system. The maintenance of high crop yields under intensive cultivation is possible only through the use of commercial fertilizers.

Although there have been tremendous increases in fertilizer use in tropical Africa over the years, utilization is still on a very small scale relative to the total needs. There is a big gap between the national requirements for fertilizers and their actual use by farmers.

**Nitrogenous fertilizers**

Straight commercial nitrogen fertilizers contain only nitrogen in high percentages. Compound nitrogen fertilizers contain one or more essential elements in addition to nitrogen.

The nitrogen in many straight and compound fertilizers is in the ammonium (NH₄⁺ ions) form, but this is quickly changed by the bacteria in the soil to the nitrate (NO₃⁻ ions) form. Most crop plants, such as cereals, take up and respond to the NO₃⁻ ions faster than to the NH₄⁺ ions, but some crops, such as rice, potatoes and grasses, are equally responsive to both forms.

On the basis of the chemical form in which nitrogen is combined with other elements in a fertilizer, nitrogenous fertilizers may be classified into four groups.

**Nitrate fertilizers:** in these fertilizers, nitrogen is combined in nitrate (NO₃⁻) form with other elements. Such fertilizers are sodium nitrate (NaNO₃), having 16% N, calcium nitrate (Ca(NO₃)₂), having 15.5% N, and potassium nitrate (KNO₃), having 13.4% N and 44% K.

Nitrate fertilizers are quickly dissociated in the soil, releasing the nitrate ion for plant absorption. As such, they are readily absorbed and utilized by the plants. The great mobility of the nitrate ion in the soil has the advantage that, even when applied to the surface of the soil, the nitrogen quickly reaches the root zone. They are therefore very often used as side and top dressings. However, there is also the increased danger of leaching of these fertilizers.

All the nitrate fertilizers are basic in their residual effect on the soil and their continued use may reduce soil acidity. Sodium nitrate, for
example, has a potential basicity of 29 kg of calcium carbonate per 100 kg of fertilizer material.

**Ammonium fertilizers:** in these fertilizers, nitrogen is combined in ammonium (NH₄) form with other elements. Such fertilizers are ammonium sulphate [(NH₄)₂SO₄], having 20% N, ammonium phosphate (NH₄H₂PO₄), having 20% N and 20% P or 16% N and 20% P; ammonium chloride (NH₄Cl), having 24–26% N; anhydrous ammonia having 82% N and aqueous ammonia, having 28% N.

When added to the soil, the ammonium ion is temporarily retained by the colloidal fraction of the soil until it is nitrified. These fertilizers are much more resistant to loss by leaching because the ammonium ion is readily adsorbed on the colloidal complex of the soil. Most ammonium fertilizers are acidic in their residual effect on the soils. For example, 100 kg of ammonium sulphate produces acidity which takes 110 kg of calcium carbonate to neutralize.

**Nitrate and ammonium fertilizers:** these fertilizers contain nitrogen in both ammoniacal and nitrate forms. Such fertilizers are ammonium nitrate (NH₄NO₃), having 32.5% N, ammonium sulphate nitrate (ASN) [(NH₄)₂SO₄·NH₄NO₃], having 26% N and calcium ammonium nitrate (CAN) [Ca(NH₄NO₃)₂], having 25% N.

These fertilizers are readily soluble in water and suitable for use under a wide variety of soils and cropping conditions. The nitrate nitrogen of these fertilizers is readily available to plants for rapid growth and the ammonium nitrogen resists leaching losses and can be utilized by the plant at a later stage. These fertilizers are acidic in their residual effect on the soils. For example, the application of 100 kg of ammonium nitrate produces acidity which requires 60 kg of calcium carbonate to neutralize.

**Amide fertilizers:** these fertilizers are carbon compounds, and so are called organic fertilizers. Important fertilizers in this group are urea [CO(NH₂)₂], having 46% N and calcium cyanamide (CaCN₂), having 22% N.

These fertilizers are readily soluble in water and easily decomposed by micro-organisms in the soil. In the soil they are quickly changed into ammoniacal nitrogen and then to nitrate form.

**General recommendations**

Yawalkar et al., (1977) have given the following general recommendations regarding the suitability of different nitrogenous fertilizers for different soil conditions and crops.

For rice, ammoniacal and ammonia-forming fertilizers such as ammonium sulphate, ammonium chloride and urea should be used. If these fertilizers are not available, ammonium-nitrate fertilizers such as ammonium sulphate nitrate, ammonium nitrate and
calcium ammonium nitrate should be used. For other field crops, all nitrogenous fertilizers are equally effective.

In acid soils, continued use of ammoniacal or ammonium-forming fertilizers should be avoided. If these fertilizers have to be used, the application of lime is desirable. All nitrate fertilizers are best suited for side and top dressing. Since they are easily leached, they should not be applied in large quantities in light sandy soils or during the rainy season. The entire recommended dose of nitrogen should be applied in 2 or 3 splits.

**Phosphatic fertilizers**
The plant nutrient content of all phosphatic fertilizers is expressed in terms of percentage of phosphorus pentoxide (P₂O₅). By custom and law the quality or grade of phosphate fertilizers is expressed as a percentage of phosphorus pentoxide equivalent. Crop plants absorb phosphorus in the form of negatively charged ions such as HPO₄²⁻ or H₂PO₄⁻.

The phosphatic fertilizers can be classified into three groups, depending on the form in which phosphoric acid is combined with calcium.

**Phosphatic fertilizers containing water-soluble phosphoric acid or monocalcium phosphate [Ca(H₂PO₄)₂]:** such fertilizers are superphosphate, ordinary or single, having 16–18% P₂O₅; double superphosphate, having 32% P₂O₅; triple superphosphate, having 46–48% P₂O₅; and ammonium phosphate, having 20% N and 20% P₂O₅, or 16% N and 20% P₂O₅. These fertilizers are quickly absorbed by the plants, as plants absorb phosphorus as H₂PO₄⁻ ions. Water-soluble phosphoric acid is rapidly transformed in the soil into a water-insoluble form. As such, there is no danger of loss of nutrients by leaching. This group of fertilizers should be used in neutral to alkaline soils and not in acidic soils. Under acidic conditions, phosphoric acid is converted into unavailable iron and aluminium phosphates.

**Fertilizers containing citric-acid-soluble phosphoric acid or dicalcium phosphate [CaHPO₄]:** such fertilizers are basic slag, containing 14–18% P₂O₅; dicalcium phosphate, containing 34–39% P₂O₅; and rhenania phosphate, containing 25–76% P₂O₅. These fertilizers are particularly suitable for acidic soils, because in such soils citrate-soluble phosphoric acid is converted into monocalcium phosphate, and there is less chance of the phosphate being fixed as iron or aluminium phosphate.

**Fertilizers containing insoluble phosphoric acid [Ca₃(PO₄)₂]:** such phosphatic fertilizers are rock phosphate, having 20–40% P₂O₅; raw bonemeal, having 20–25% P₂O₅ and 3–4% N and steamed
bonemeal, having 22% P₂O₅. These fertilizers are well suited for strongly acidic soils or organic soils which require larger quantities of phosphatic fertilizers to raise the soil fertility. The availability of these fertilizers is increased when they are ploughed under with organic material such as a green manure crop.

**Phosphorus retention in soils**

In phosphate fertilization, 'fixation' is a problem, that is, some of the phosphoric acid becomes unavailable as it becomes fixed or retained in the soil. The retention of phosphorus depends on the following factors.

**Type of clay:** soils containing a large amount of clay will fix more phosphorus than those containing a small amount. Phosphorus is retained to a greater extent by 1:1 (e.g. kaolinitic) than by 2:1 (e.g. montmorillonite) clays. Soils high in 1:1 clays will fix or retain larger quantities of added phosphorus than those containing the 2:1 type.

**Soil reaction:** in most soils, phosphorus availability is at a maximum in the pH range of 5.5–7.0, decreasing as the pH drops below 5.5 and also as it goes above 7.0. At low pH values the retention results largely from the reaction with iron and aluminium and their hydrous oxides. As the pH increases, the activities of these reactants are decreased. Above pH 7.0 the ions of calcium and magnesium, as well as the presence of the carbonates of these metals in the soil, cause precipitation of the added phosphorus, and its availability again decreases.

**Temperature:** the soils of the warmer climates are generally much greater fixers of phosphorus than the soils of the temperate regions, because the warmer climates give rise to soils with higher contents of hydrous oxides of iron and aluminium.

**Organic matter:** the addition of organic matter to the soil may increase the availability of soil phosphorus. The turning under of stubble or green manures results in a better utilization of phosphorus by subsequent crops.

**Phosphorus status of the soil:** there is a pronounced relationship between the amount of fixation of added fertilizer phosphorus and the degree of phosphorus saturation of the soil or the amount of phosphorus previously fixed by the soil. Larger amounts of added phosphorus are fixed when the amount of phosphorus present is low.

**Time of reaction:** the greater the time the soil and added phosphorus are in contact, the greater the amount of fixation. How long the plants will be able to utilize the added phosphate depends on the phosphate fixing capacity of the different soils. On some soils with a
high fixing capacity, this period of utilization may be short, whereas with other soils this period may last for months or even years.

**Effectiveness of phosphatic fertilizers**

Phosphatic fertilizers are most effective when the following principles are adhered to:

* granular fertilizers with a high degree of water-solubility are more effective on acid and neutral soils than powdered fertilizers containing the same proportion of water-soluble phosphorus when these two are mixed with the soil
* on acid and neutral soils, band application of powdered fertilizer with a high degree of water solubility will give better results than mixing the fertilizers with the soil
* on calcareous soils the best results may be achieved when water-soluble phosphate in powdered form is thoroughly mixed with the soil
* short-duration fast-growing crops and those with restricted root systems generally require a fertilizer containing a high proportion of water-soluble phosphorus
* when the amount of phosphate to be applied is limited, the greatest crop response will always be obtained with water soluble materials and when the material is applied in a band
* the maximum response will not be obtained from added phosphate unless adequate quantities of the other plant nutrients, including the secondary and micronutrients, are present.

**Potassic fertilizers**

All potassic fertilizers supply potassium (K), an essential plant nutrient. The quality or grade of potassic (or potassium) fertilizers is expressed as a percentage of potassium oxide (K₂O) equivalent.

All the potassium fertilizers consist essentially of potassium in combination with chloride, sulphate, or nitrate. Some double salts exist, such as potassium-magnesium sulphate. Almost all the potassic fertilizers are water soluble. The following are the important potassic fertilizers: potassium chloride (KCl) or muriate of potash, having 60–63% K₂O; potassium sulphate (K₂SO₄), having 50–53% K₂O; potassium-magnesium sulphate (K₂SO₄·MgSO₄), having 22% K₂O; potassium nitrate (KNO₃), having 13% nitrogen and 44% K₂O and potassium metaphosphate (KPO₄), having 40% K₂O and 60% P₂O₅.

**Potassium retention in soils**

Like phosphorus, the conversion of potassium to the slowly available or fixed forms reduces its immediate value as a plant nutrient.
However, it must not be assumed that potassium fixation is completely unfavourable. There are certain beneficial aspects associated with this phenomenon.

Potassium fixation, in the first place, results in the retention of potassium which might otherwise be lost by leaching. Secondly, fixed potassium tends to become available over a long period of time and is thus not lost completely to plants.

The continued addition of potassium not only decreases the potassium fixing powers of soils, but also increases crop yields. As with other essential elements, an increase in the level of available soil potassium decreases the crop responses obtained from further fertilizer application of that element.

Effectiveness of potassic fertilizers
From the point of view of nutrition, all potassic fertilizers are equally available to plants because all of them are readily soluble in water. The low grade potassium fertilizers have a greater content of soluble salts per kg of potassium supplied. With some crops and with some methods of fertilizer application, the higher salt content may be injurious to plant growth. Potassium fertilizers containing sulphur, magnesium or sodium have some additional agronomic importance on some soils, because of these other elements present. Tobacco is a crop which is extremely sensitive to excessive amounts of chloride, as this impairs the burning quality. For tropical root and tuber crops generally, high quantities of chloride tend to depress yields. This means that muriate of potash should be avoided or used with caution.

Fertilizers Supplying Secondary and Micronutrients

Fertilizers supplying secondary nutrients
Calcium, magnesium and sulphur may be of secondary importance to the fertilizer manufacturers but they are as essential to plant growth as the major plant nutrient elements. No special fertilizers are manufactured simply to supply these elements, but several fertilizer materials contain them in significant quantities.

Calcium is indirectly added to the soil through fertilizers and soil amendments and directly as lime. Several fertilizers used these days contain calcium, e.g. calcium nitrate (27%) and superphosphates (27–46%).

Magnesium is obtained mainly from dolomite limestone (CaCO₃·MgCO₃), a material used to correct soil acidity. In contrast to calcium, few fertilizers contain large amounts of magnesium. Calcium nitrate and monoammonium phosphate contain 2.5 and
0.5% MgO respectively. Fertilizing materials supply magnesium as magnesium sulphate or potassium magnesium sulphate.

Sulphur is required by plants in about the same quantities as phosphorus. Unlike calcium and magnesium, sulphur is found in the earth’s crust, in organic matter, in the atmosphere around industrial centres, and in rain. Sulphur is used as elemental sulphur, sulphide or sulphate forms. There are many sulphur-containing fertilizer, the most important of which are ammonium sulphate (23.4%), ammonium phosphate sulphate (15%), potassium sulphate (17.0%) and single superphosphate (14.0%).

**Fertilizers supplying micronutrients**

Under the traditional bush-fallow system of cultivation in Africa, hardly any deficiency of any micronutrient could be seen, but where the intensive system of cultivation is practised, deficiency symptoms of one or more micronutrient have been observed. It is feared that unless timely action is taken, the level of deficiency will continue to increase, causing progressive reduction in yields.

**Copper:** Copper deficiencies have been reported from some countries. The average copper content in soils is reported to range between 2–100 ppm. Copper can be applied by spraying a solution of soluble or slightly soluble salts on the plant leaves or by applying the fertilizer materials to the soil. Copper sulphate (CuSO₄·5H₂O) containing 25.5% copper and 12.8% sulphate is commonly applied in both ways, as is copper ammonium phosphate, containing 30% copper.

**Zinc:** the average zinc content in soils ranges from 10–300 ppm but its concentration in the soil is not an indication of its availability to plants. Its availability depends on soil pH, the nature of the clay minerals, and the form in which it exists. Of the micronutrients, zinc is most commonly deficient. Zinc sulphate, containing about 36% zinc, is a popular fertilizer material. It can be applied to the soil, usually at a rate of 40–80 kg/ha, and can also be sprayed.

**Iron:** the iron content in the soil is much higher than that of most other micronutrients. Iron deficiency is believed to be caused by an imbalance of other metallic ions. Iron sulphate (FeSO₄·7H₂O) is the inorganic salt most commonly used in sprays for controlling iron deficiency. Solutions containing 4–6% iron sulphate are applied at rates of 15–25 l/ha, depending on the crop. The other widely used group of iron compounds are the iron chelates containing 6–12% iron.

**Boron:** Boron occurs in most soils in extremely small quantities, ranging from about 20–200 ppm. Borax (Na₂B₄O₇·10H₂O),
containing 10.6% boron, is the most popular of the boron-containing fertilizers.

**Manganese**: the manganese content of the soil varies from a trace to several thousand kg/ha. Manganese sulphate is the most popular manganese fertilizer material. It contains about 26% manganese and 15% sulphur and can be used at 30–60 kg/ha. Another manganese fertilizer material is manganous oxide, in two forms – one containing 46% and the other 65% manganese.

**Molybdenum**: the average molybdenum content of soil is about 2 ppm. It is required by plants in very small quantities. The several compounds available to supply fertilizer molybdenum include ammonium and sodium molybdate and molybdenum trioxide. These materials are normally mixed with the NPK fertilizer and are applied at rates equivalent to 150 g–2 kg/ha. They can also be applied as foliar sprays.

**Compound Fertilizers**

Compound fertilizers supply two or three of the major plant nutrient elements (i.e. nitrogen, phosphorus and potassium). They are produced by mixing the straight fertilizers, e.g. ammonium nitrate, ammonium phosphate and muriate of potash, or by more complex chemical processes.

Compound fertilizers are well mixed by machine, are granulated and store well. This is a great saving in labour. Fertilizers mixed on the farm do not store well.

The chemical composition of compound fertilizers is usually given as the ratios of nitrogen, phosphorus and potassium expressed as elemental N, P₂O₅ and K₂O respectively. A 15:20:10 compound fertilizer therefore contains 15% N, 20% phosphorus expressed as P₂O₅, and 10% potassium expressed as K₂O.

**Materials used in fertilizer mixtures**

The following groups of materials are used in manufacturing fertilizer mixtures.

**Plant nutrient suppliers**: these are straight or complex fertilizers added to supply the plant nutrients mentioned in the grade and are the primary ingredients of fertilizer mixtures.

**Conditioners**: to prepare mixed fertilizers in good drilling condition and to reduce caking, low-grade organic materials are usually added at the rate of about 40 kg per tonne. These materials, known as conditioners, may be tobacco stems or groundnut or rice hulls.

**Neutralizers of residual acidity**: if the nitrogenous fertilizers used in the mixture are acidic in nature, like ammonium sulphate or urea, a basic material such as dolomitic limestone is added to
counteract the acidity. Such a material is known as a neutralizer of residual acidity.

_**Filler:**_ the filler is the make-weight material added to a fertilizer mixture. It is added to make up the difference between the weight of the added fertilizers required to supply the plant nutrients and the desired quantity of fertilizer mixture. The common filler materials are sand, soil, ash, and other waste products.

**Grades of fertilizer mixtures**

A large number of grades of fertilizer mixtures are available. They may be divided into low- and high-grade mixtures. Low-grade mixtures are 6:12:6, 5:10:10, 9:9:0 etc., and high-grade mixtures are 15:15:15, 20:20:20 etc. Farmers normally prefer to use high-grade mixtures. The advantages of using high-grade fertilizers are:

* low cost per unit of plant food
* lower transportation costs
* less storage space required
* less labour in handling
* increased speed of application in the field.

**Soil Amendments**

Soil amendments are the substances used for correcting the acidity or alkalinity of the soil. In high rainfall areas, due to the leaching of bases, acidic soils are formed, while in low rainfall regions in arid and semi-arid conditions, saline and alkaline soils occur.

**Soil reaction or soil pH**

Soils vary considerably in degree of acidity or alkalinity, or in reaction. The normal range is expressed in pH values as given in Table 3.

<table>
<thead>
<tr>
<th>Range in soil reaction</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extremely acid</td>
<td>below 4.5</td>
</tr>
<tr>
<td>Very strongly acid</td>
<td>4.5-5.0</td>
</tr>
<tr>
<td>Strongly acid</td>
<td>5.1-5.5</td>
</tr>
<tr>
<td>Medium acid</td>
<td>5.6-6.0</td>
</tr>
<tr>
<td>Slightly acid</td>
<td>6.1-6.5</td>
</tr>
<tr>
<td>Neutral</td>
<td>6.6-7.3</td>
</tr>
<tr>
<td>Mildly alkaline</td>
<td>7.4-7.8</td>
</tr>
<tr>
<td>Moderately alkaline</td>
<td>7.9-8.4</td>
</tr>
<tr>
<td>Strongly alkaline</td>
<td>8.5-9.0</td>
</tr>
<tr>
<td>Very strongly alkaline</td>
<td>9.1 and above</td>
</tr>
</tbody>
</table>
Liming of acidic soils: liming, as the term applies to agriculture, is the addition of any calcium or calcium- and magnesium-containing compound to the soil for reducing acidity. For this purpose, calcium oxide, calcium hydroxide, calcium carbonate, calcium magnesium carbonate and calcium silicate slags are used.

Neutralizing or calcium carbonate equivalent of liming materials: liming materials differ markedly in their ability to neutralize acids. The value of limestone for this purpose depends on the quantity of the acid that a unit weight of the material will neutralize. Pure calcium carbonate is the standard against which other liming materials are measured. The neutralizing value of several compounds are given in Table 4.

<table>
<thead>
<tr>
<th>Material</th>
<th>Neutralizing value % pure CaCO₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium oxide (CaO)</td>
<td>179</td>
</tr>
<tr>
<td>Calcium hydroxide [Ca(OH)₂]</td>
<td>136</td>
</tr>
<tr>
<td>Calcium carbonate (CaCO₃)</td>
<td>100</td>
</tr>
<tr>
<td>Calcium-magnesium carbonate [CaMg(CO₃)₂]</td>
<td>109</td>
</tr>
<tr>
<td>Calcium silicate (CaSiO₃)</td>
<td>86</td>
</tr>
</tbody>
</table>

Methods of applying lime: lime should be applied before ploughing, or applied on ploughed land and then disked or mixed into the soil. When large quantities of lime are required, it is advisable to apply the required amount in two or three splits rather than in one heavy application. On strongly acidic soils, where 7–15 tonnes of lime are required for one hectare, half the quantity should be applied before ploughing and the remaining half applied and disked after ploughing. When the lime requirement is below 4–5 tonnes per hectare, the entire amount should be applied and disked in at one time, 8–10 days before sowing.

Reclaiming saline and alkaline soils
Chemical amendments are used to reclaim saline and alkaline soils. The principal function of these amendments is to furnish soluble calcium to replace exchangeable sodium or to neutralize alkaline salts with acid. The following chemical amendments are used: gypsum (CaSO₄·2H₂O), sulphur (S), iron sulphate (FeSO₄) and limestone (CaCO₃). Of these, gypsum is the most widely used material.

The requirement of gypsum in relation to soil pH and soil type varies. Light soils require less gypsum than medium or heavy soils. The application of gypsum at a shallow depth (10–15 cm) gives higher crop yields than when it is applied deeper than 15 cm.
After gypsum, sulphur is the most effective in improving saline and alkaline soils. One tonne of sulphur is equivalent to 5.38 tonnes of gypsum, 6.64 tonnes of iron sulphate, and 3.13 tonnes of limestone.

**Time and Method of Fertilizer Application**
Fertilizers are applied to crops to supply the nutrients that are not present in sufficient quantities in the soil. The purpose of an adequate fertilization programme is to supply, year after year, the amount of nutrients that will result in sustained maximum net returns. This means that fertilizers are to be used in the most efficient way. To achieve maximum benefit from fertilizers it is most essential to apply them at the right time and in the right place.

**Time of application**
Since nitrogen is required throughout the growth period, and nitrogenous fertilizers are lost through leaching, it is better not to apply too much nitrogen at one time. The application of split doses throughout the growing period will ensure that the plants will not suffer from nitrogen deficiency. On lighter soils, to reduce losses due to leaching, more frequent or split application of nitrogenous fertilizers is desirable. This is less important on heavy-textured soils.

Phosphorus is required in greater quantities during the early growth period and as all phosphatic fertilizers become available to the growing plants slowly, it is always recommended that the entire quantity of phosphatic fertilizers be applied in one dose before sowing or planting. On acid soils, it is advisable to apply bone meal or rock phosphate a week or fortnight prior to sowing.

Potassium behaves partly like nitrogen and partly like phosphorus. Like nitrogen, it is absorbed right up to the harvesting stage but like phosphate, it becomes available slowly. It is therefore always advisable to apply the entire quantity of potassium at sowing time.

**Methods of application**
A fast start and continued nutrition is essential for sustained maximum profit. Merely applying fertilizer does not ensure that it will be taken up by the plant. It is important to place some of the fertilizer where it will intercept the roots of the young plant and to place the bulk of the nutrients deeper in the soil.

Nitrogenous fertilizers are easily soluble in water and have mobility, so they can be applied on the soil surface.

Since phosphorus moves slowly from the point of placement, it should be placed closer to the plant roots. To reduce phosphate
fixation, phosphatic fertilizers should be so placed that they come into minimum contact with the soil particles and are close to the plant roots.

Since phosphate fertilizers move slowly in the soil, they should also be placed near the root zone.

Based on these principles, the following methods are used to apply fertilizers.

**Solid fertilizer** is either broadcast at planting or used as top dressing. Placement can be either plough-sole or deep placement, band placement or side dressing.

**Liquid fertilizer** is used as a starter solution, for foliar application or spray fertilization, for direct application to the soil, or for application through irrigation water.

**Broadcast at planting**: the fertilizer is spread over the entire soil area to be fertilized with the main objective of distributing the whole quantity of fertilizer evenly and uniformly and incorporating it in the plough layer.

**Top dressing**: when the crop is closely spaced, like wheat or barley, or sown broadcast, applying the nitrogenous fertilizer in the standing crop is known as top dressing. One or more top dressings of nitrogenous fertilizers may be applied to provide nitrogen at the time of greatest need of the crop. Top dressing of phosphorus and potassium is ordinarily done only on pasture lands which occupy the land for several years.

In top dressing, care must be taken not to spread fertilizers on wet leaves because this may burn or scorch them.

**Side dressing** is also a form of top dressing. The difference is that in side dressing the fertilizer is spread between the rows or around the plants.

**Plough-sole placement** is the placement of fertilizer in a continuous band on the bottom of the furrow during the process of ploughing. Each band is covered as the next furrow is opened. This method is useful in areas where the soil becomes quite dry down to a few centimetres below the soil surface during the growing season, and especially for soils with a heavy clay pan a little below the plough-sole. By this method, the fertilizer is placed in moist soil where it can become easily available to the growing plants during the dry season.

**Band placement** refers to the application of fertilizers into the soil close to the seed or plant and is employed when relatively small quantities of fertilizers are to be applied. When fertilizers are placed along with, or close to, the seeds or plants in bands or pockets, the roots of the young plant are assured of an adequate supply of nutrients and this promotes rapid early growth. This method
of placement also reduces the fixation of phosphorus and potassium.

When the plants are spaced 100 cm or more apart on both sides, fertilizers are placed close to the plant in a band on one or both sides. This is known as hill placement. The length and depth of the band and the distance from the plant varies with the crop and the amount of fertilizer. For applying small amounts of fertilizers, hill placement is usually most effective. This method is very useful for fruit trees.

When seeds or plants are sown close together in a row, the fertilizer is put in continuous bands on one or both sides of the row. This method of application is known as row placement, and is used for potatoes, maize, tobacco, cotton, sugarcane, etc.

**Starter solution:** solutions of fertilizers, generally consisting of N, P and K in the ratios 1:2:1 or 1:1:2, are applied to young vegetable plants at the time of transplanting. These solutions are known as starter solutions and are used in place of the watering that is usually given to help the plants to establish. Only a small amount of fertilizer is applied as a starter solution.

**Foliar application:** it has been well established that plant nutrients are also absorbed through the leaves of the plant. Foliar application refers to the spraying of the leaves of growing plants with suitable fertilizer solutions. These solutions may be prepared in low concentrations (usually 3–6%) to supply one or more plant nutrients. As solutions of low concentrations are used, only small quantities of nutrients can be applied in one single spray, hence several applications are needed for moderate to high fertilizer rates. It is therefore used in practice mainly to correct micronutrient deficiencies. With foliar application, plant response is quicker than when the micronutrients are supplied through the soil. Foliar application is costly compared to soil application, unless it is combined with the spraying of pesticides.

**Direct application into the soil:** with the help of special equipment, anhydrous ammonia (a liquid fertilizer) and nitrogen solutions can be applied directly into the soil. There is very little plant injury or wastage of ammonia if the material is applied about 10 cm below the seed, and the soil is moist.

**Application through irrigation water:** straight or mixed fertilizers which are easily soluble in water are allowed to dissolve in the irrigation stream. The nutrients are thus carried into the soil in solution. The fertilizers most commonly applied through irrigation water are nitrogenous fertilizers.
6
IRRIGATION AND DRAINAGE

IRRIGATION
Irrigation is generally defined as the artificial application of water to the soil for the purpose of supplying the moisture essential for plant growth. Irrigation water is supplied to supplement the water available from rainfall.

Irrigation is an age-old art, as old as civilization. The pressure of survival and the need for additional food supplies to meet the demands of increasing populations is necessitating a rapid expansion of irrigation throughout the world. Irrigation is not only important for the arid regions but is becoming equally important in humid regions, as an important feature in more recent times has been the recognition of the advantages of irrigation even in areas normally considered to have sufficient rainfall for reasonable crop production. In such areas, if the water balance in the crop root zone is insufficient even for a short period (in other words, if water requirement is greater than rainfall), supplementary irrigation can be very advantageous. Thus irrigation is becoming a basic part of well-developed agriculture throughout the world.

While irrigation has been widely practised for a very long time in Egypt, this is not the case in regions south of the Sahara. The absence of irrigation south of the Sahara can perhaps be explained by the general lack of population pressure, but in recent times increasing population and general increased demands on agricultural production have changed this. In Africa, increasing population is causing a decrease in the fallow period of the traditional bush-fallow system of cultivation, with a resultant drop in fertility and yields. As the soil loses its humus content, it becomes less moisture retentive, and hence rainfall is less effective. In such conditions, the advantage of irrigation is recognized.

Soil-Plant-Water Relationships
Soil-plant-water relationships relate to the properties of soils and plants that influence the movement and retention of water in the soil
and its use by the plants. Water is essential to the life and growth of plants and the soil provides the room for the water to be used by plants. The rate of entry of water into the soil and its retention, movement and availability to plants roots are greatly influenced by the physical properties of the soil, such as soil texture, structure, pore space and bulk density. These properties have been described in detail in Chapter 3.

**Soil-water relationship**

Water is absorbed by the plant roots and lost by the leaves during transpiration. Most of the water absorbed is lost through transpiration. It is the balance between water intake and loss which is important. If there is not much water available for absorption to compensate for transpiration loss, a water deficit develops in the plants. The availability of water can be considered in terms of the total quantity of water available in the root zone of the crop. When there is rain or when the field is irrigated, the soil is said to be under saturation capacity or maximum water holding capacity. The tension of water at saturation capacity is almost zero and it is equal to free water. Soon after rainfall or irrigation, the draining of excess water from the soils starts under the constant pull of gravity.

Sandy soils drain readily, while clay soils drain very slowly. Excess water is drained out of the root zone in sandy soils only a few hours after rainfall or irrigation, whereas it may take two or more days in clay soils. The rate of drainage is more rapid immediately after rainfall or irrigation and decreases constantly. On the average, 48 hours are required before the rate of drainage decreases rather sharply.

After the draining out of the surplus water from the root zone, the remaining soil water can vary from between field capacity and a condition in which it reduced to a microscopic layer around individual soil particles, termed the permanent wilting point. Both these extreme conditions are unfavourable for plant growth, the former because water-logging and the exclusion of oxygen from the root environment occurs, and the latter because water is held too tightly by the soil and the resistance to the movement of water becomes very high. In both these conditions, water is not available to the plants, but between these two points there is a range of conditions in which water becomes available, although the degree of availability varies considerably with crop species.

**Field capacity** is the amount of water (on dry weight basis) a well-drained soil holds after the rate of downward soil water movement has decreased to the extent that further drainage is slow. This situation usually exists one to three days after the soil has been
thoroughly wetted by rain or irrigation. The field capacity is the upper limit of available moisture range in soil. The soil moisture tension at field capacity varies from soil to soil, but it generally ranges from 1/10 atmosphere in sandy soils to 1/3 atmosphere in clay soils. 1 atmosphere is equal to about 1 kg per sq cm.

**Permanent wilting point** is the lower limit of water availability at which permanent wilting of a particular plant occurs. Wilting point, or the wilting co-efficient, is the soil moisture content at which plants can no longer obtain sufficient moisture to satisfy moisture requirements and remain wilted unless water is added to the soil. At the permanent wilting point the film of water around the soil particles is held so tightly that roots in contact with the soil cannot remove the water at a sufficiently rapid rate to prevent wilting of the plant leaves. Permanent wilting point is entered when the soil moisture tension ranges from 12–18 atmosphere. A widely accepted value for permanent wilting point is 15 atmosphere.

**Available soil water** is the difference in water (moisture) content of the soil between field capacity and permanent wilting point. This represents the moisture which can be stored in the soil for subsequent use by plants. The amount of available water decreases as wilting point is reached. Plant growth is adversely affected with the increasing soil moisture tension from field capacity to wilting point. The amount of available water in soil is dependent mainly on the percentage of sand, silt and clay of the soil. Generally, the more silt and clay in the soil, the greater the availability of water.

In semi-arid regions, the lower level of soil water availability at which growth or yield is not retarded is generally 50% of the total available water.

**Measurement of soil moisture**

The measuring of soil moisture is important in the scheduling of irrigation and in estimating the amount of water to apply in each irrigation. Measuring the changes in soil moisture storage with time is important for estimating evapotranspiration. The principal methods of measuring soil moisture are firstly by measuring the amount of water in a given amount of soil and secondly by measuring the stress or tension under which the water is held by the soil. The first method is a slow and time-consuming one, and is therefore not common, but the second method is now commonly used.

The following instruments and techniques are used to measure the stress or tension under which the water is held by the soil:

* tensiometer
* pressure membrane and pressure plate technique
* electrical resistance block
* neutron moisture meter.
For undergraduate students the tensiometer and the electrical resistance block are important.

**Tensiometer:** this provides a direct measure of the tenacity with which water is held by soils. Tensiometer readings reflect soil-moisture tension only, i.e. they indicate the relative wetness of the soil surrounding the porous cup of the tensiometer. They do not provide direct information on the amount of water held in the soil. Tensure measurements are useful in deciding when to irrigate, but they do not indicate how much water should be applied. A special
moisture characteristic curve for the particular soil is needed to convert moisture tension measurements into available-moisture percentages (Fig. 15).

A tensiometer consists of a porous ceramic cup filled with water, a tube also filled with water, and a vacuum gauge. The scale on the vacuum gauge is generally calibrated in hundredths of an atmosphere (Fig. 16). The tensiometer is made airtight before it is placed in the soil.

When the tensiometer is placed in the soil where the tension measurement is to be made (Fig. 17), the water inside the porous cup comes into hydraulic contact and tends to equilibrate with the soil water through the pores in the ceramic cup. The water in the tensiometer is generally at atmospheric pressure, whereas water in the soil is generally at subatmospheric pressure. The soil water exercises suction which draws out a certain amount of water from the tensiometer, causing a drop in the hydrostatic pressure in the vacuum gauge. Any increase in tension because of the drying of the soil causes an increase in vacuum gauge reading. Conversely, an increase in soil-water content reduces tension and lowers the reading.

A tensiometer generally measures the tension below 1 atmosphere. In practice, the useful limit of most tensiometers is at about 0.85 atmosphere. The limited range of tension measurable by a tensiometer is not serious, since it generally encompasses the greater part of the soil wetness range. Although the tensiometer
does not satisfactorily measure the entire range of available moisture in all soil types, it is probably the best field instrument to use to determine moisture condition in the wet range. It is very suitable for sandy soils since in these soils a large part of the moisture available to plants is held at a tension of less than 1 atmosphere. It is less suited for fine-textured soils in which only a small part of the available moisture is held at a tension of less than 1 atmosphere.

The general practice is to place the tensiometer at one or more soil depths representing the root zone, and to irrigate when the tensiometer indicates some prescribed values. The use of several tensiometers at several depths can (with the help of calibration curves) indicate the amount of water needed in irrigation.

To install a tensiometer into the soil, a hole is made in the soil to the desired depth by driving a solid steel rod of the same diameter as the tensiometer, so that the walls of the ceramic cup are in close contact with undisturbed soil and roots at the desired depth. After the tensiometer is installed, the soil at the ground surface is pressed around it, and piled up slightly so that water will not collect and seep down along the tube of the tensiometer.

**Electrical resistance blocks** are made of various porous materials such as gypsum, nylon, fibre glass, plaster of Paris or a combination of these materials. The blocks are generally rectangular in shape and have a pair of electrodes. A convenient size of gypsum block is 5.5 cm long, 3.75 cm wide and 2 cm thick (Fig. 18).

When the blocks are buried in the soil at the desired depths, the electrode lead wires are taken out to the soil surface, well secured, and protected against rain.

When porous blocks are embedded in the soil, their moisture content comes into equilibrium with the soil moisture. The electrical resistance between the two electrodes varies with the moisture content of the porous blocks, which are calibrated against a range of moisture content. To measure the resistance, the electrode lead
Fig. 19  Installation of conductivity blocks in the root zone and measuring the resistance

wires are connected to a resistance meter that measures the changes in electrical resistance in the blocks.

In order to obtain readings which are representative of the area, the blocks must be properly installed in the soil. It is necessary that the blocks have close contact with undisturbed soil. A satisfactory procedure is to force the blocks into undisturbed soil along the sides of a trench dug for the placement of the blocks. After placement, the trench is filled up (Fig. 19).

Plant-water relationships
Almost every process occurring in plants is affected by water availability in the root zone. Water is absorbed by the plant roots and lost by the leaves during transpiration. It is the balance between water intake and loss which is important. If there is not much water for absorption to compensate for transpiration loss, a water deficit develops in the plants.

Evapotranspiration and consumptive use: usually both sources of water loss, i.e. transpiration and evaporation, are estimated together and are called evapotranspiration (ET). Transpiration refers to water being passed through the leaves of the plant into the
atmosphere. Evaporation refers to water evaporating from adjacent soil and water surfaces, or from the surface of the leaves of the plant. Consumptive use (Cu or U) refers to the total water lost by evapotranspiration and the water used by the plant to build plant tissue. Consumptive use, and therefore also evaporation, is influenced by temperature, radiation, wind velocity, humidity, length of growing season, stage of development of the plant, type of foliage, and nature of the leaves. Variation in consumptive use rate occurs from day to day because of changes in the weather. A hot, dry, windy day will increase the rate, whereas a cool and cloudy day will decrease the rate of consumptive use. In most crops, the beginning of flowering and the end of the vegetative growth stages are the stages of peak consumptive use.

Potential evapotranspiration: the concept of potential evapotranspiration (PET) can be visualized as the integral effect of all the climatic factors governing the evapotranspiration process. It may be defined as the evapotranspiration (ET) that occurs when the ground is completely covered by actively growing vegetation and where there is no limitation in the soil moisture. It may be considered to be the upper limit of evapotranspiration for a crop in a given climate.

Water requirement: the water requirement (WR) of a crop may be defined as the quantity of water, regardless of its source, required by a crop in a given period of time for its normal growth under field conditions at a specific place. Water requirement includes the losses due to evapotranspiration (ET) or consumptive use (Cu) plus the losses during the application of irrigation water and the quantity of water required for special operations such as land preparation, transplanting, leaching, etc. It may thus be formulated as follows: WR = ET or Cu + application losses + special needs.

Water requirement is therefore a demand for water. The supply of water comes from any of the sources of water, viz., irrigation water (IR), effective rainfall (ER) (i.e., utilisable rainfall and not the total rainfall) and soil profile contribution (S) including that from shallow water tables. Water supply (WS) can thus be formulated as: WS = IR + ER + S.

Irrigation requirement
The field irrigation requirement (IR) of a crop, therefore, refers to the water requirement of the crop, excluding effective rainfall and the contribution from the soil profile, and may be formulated as: IR = WR - (ER + S).

A farm’s irrigation requirement depends on the irrigation needs of the individual crops, their area and losses in the farm water distribution systems, mainly by seepage. The irrigation require-
ment of an outlet command area includes the irrigation requirements of individual farm holdings and the loss in the conveyance and distribution system.

**Net irrigation requirement** is the amount of irrigation water required to bring the soil moisture level in the effective root zone to field capacity. Thus it is the difference between field capacity and the soil moisture content in the root zone before starting irrigation.

**Gross irrigation requirement** is the total amount of water applied through irrigation. In other words, it is the net irrigation requirement plus losses in water application and other losses. Gross irrigation requirement can be determined for a field, a farm, an outlet command area, or an irrigation project, depending on the need, by considering the appropriate losses at various stages of the crop.

Gross irrigation requirement (in field) = net irrigation requirement divided by irrigation efficiency. For example, if the net amount of irrigation is 10 cm and the irrigation efficiency is 70%, the gross amount of water to be applied to the field is 10 cm divided by 0.70 = 14.29 cm.

**Irrigation efficiency** has been defined as the percentage of irrigation water that is stored in the soil and available for consumptive use by crops (Grassi, 1987). The ratio between water requirement and irrigation requirement is a measure of irrigation efficiency. It indicates how efficiently the available water supply is being used. The principal factors influencing irrigation efficiency are the design of the irrigation system, the degree of land preparation, and the skill and care of the irrigator. Loss of irrigation water occurs in the conveyance and distribution system, non-uniform distribution of water over the field, percolation below crop root zone, and with sprinkler irrigation, evaporation from the spray and retention of water on the foliage. These losses can be minimized by adequate planning of the irrigation system, proper design of the irrigation method, proper land preparation, and the efficient operation of the system.

**Irrigation frequency** refers to the number of days between any two subsequent irrigations during periods without rainfall. It depends on the consumptive use rate of a crop and the amount of available moisture in the crop root zone. It is a function of crop, soil and climate. Sandy soils are irrigated more often than fine-textured soils. Moisture-use rate increases as the crop grows and the days become longer and hotter. In general, irrigation should start when about 50% of the available moisture has been used from the zone in which most of the roots are concentrated. A record of the growth stages of the crop with reference to the critical periods of growth is also kept with a view to determining the frequency of irrigation.
Irrigation scheduling
The number and timing of irrigations vary widely for different crops. Earlier concepts for scheduling were based on the soil water regime in which the water content at field capacity (the upper limit of the regime) was considered as 100% available for crop growth, and that at the permanent wilting point as 0% available. About 50% available water was accepted as the lower limit of the regime and it was taken as a criterion for scheduling irrigation. Later on it was realised that climatic parameters play a predominant role in governing the water need of crops. This led to the concept of evapotranspiration, which was then used as the criterion for timing irrigations. The latest approach for scheduling irrigations is the plant water status itself. This may be considered as an ideal criterion as the plant is a good integrator of soil, water and climatic factors.

Crop response to water at different stages of growth
It has been found that the water requirements of a crop vary with the different stages of its growth. When water is in abundance, irrigation can be given whenever needed, but when the water supply is limited, it is necessary to take into account the critical stages of crop growth with respect to moisture. The term critical stage is commonly used to define the stage of growth when plants are most sensitive to water shortage. Each crop has certain critical stages at which, if there is a shortage of moisture, yield is reduced drastically. Therefore, when there is a shortage of water, it is better to take care of the critical stages first to obtain increased water use efficiency. The critical stages of some crops are given in Table 5.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Critical periods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>Crown root initiation, heading, flowering and grain formation</td>
</tr>
<tr>
<td>Rice</td>
<td>Tillering, heading and flowering</td>
</tr>
<tr>
<td>Maize</td>
<td>Flowering and milk-ripe stage, i.e. tasselling to hard-dough stages</td>
</tr>
<tr>
<td>Sorghum</td>
<td>Boot to heading stage</td>
</tr>
<tr>
<td>Groundnuts</td>
<td>Flowering and pod development</td>
</tr>
<tr>
<td>Cotton</td>
<td>Start of flowering and during boll development</td>
</tr>
</tbody>
</table>

The following terms are used to describe the growth and developmental stages of cereals in relation to irrigation (Salter and Goode, 1967).
<table>
<thead>
<tr>
<th>Stage</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germination</td>
<td>The appearance of the radicle</td>
</tr>
<tr>
<td>Tillering</td>
<td>The formation of tillers, i.e. branches produced from the base of the stem</td>
</tr>
<tr>
<td>Jointing</td>
<td>The stage where two nodes can be seen, i.e. the beginning of shooting</td>
</tr>
<tr>
<td>Shooting</td>
<td>The stage of elongation of internodes</td>
</tr>
<tr>
<td>Booting</td>
<td>The end of the shooting stage and just prior to the emergence of the ears</td>
</tr>
<tr>
<td>Heading/Earring</td>
<td>The emergence of the ear from the tube formed by the leaf sheaths</td>
</tr>
<tr>
<td>Flowering</td>
<td>The opening of the flowers. In the case of maize, this is often divided into 'tasselling' and 'siking', being the time of appearance of the male and female flowers, respectively.</td>
</tr>
<tr>
<td>Grain formation</td>
<td>The period of grain development from fertilization until maturity. The period can be sub-divided as follows:</td>
</tr>
<tr>
<td>Milk-ripe</td>
<td>Grain contents have a milky consistency</td>
</tr>
<tr>
<td>Soft-dough</td>
<td>Grain contents have a doughy consistency</td>
</tr>
<tr>
<td>Waxy-ripe</td>
<td>Grain contents have a waxy appearance</td>
</tr>
<tr>
<td>Full-ripe</td>
<td>Grain contents hard</td>
</tr>
<tr>
<td>Dead-ripe</td>
<td>Grain ripe for cutting</td>
</tr>
</tbody>
</table>

**Irrigation Methods**

Irrigation methods vary in different parts of the world and on different farms in the same area because of differences in soil, topography, water supply, crops and customs. There are four methods:

* surface irrigation (floodling, check basin method, border strip method, furrow method and corrugation method)
* overhead irrigation (sprinkler irrigation)
* subsurface irrigation
* drip irrigation.

**Surface irrigation**

In the surface methods of irrigation, water is applied directly to the soil surface from a channel located at the upper reach of the field. Highly efficient irrigation can be achieved in surface methods by an appropriate combination of the size of the irrigation stream, the size, shape and slope of the irrigation bed, the infiltration rate of the soil and the plant population. It is often convenient to express the requirement of the irrigation stream in terms of the rate of water flow per unit width of the border, such as in litres per second per metre of border width. This value multiplied by the width of the border is the size of the irrigation stream that should be delivered into each border. Coarse-textured soils with high infiltration rates require larger streams to spread over the entire strip rapidly and
avoid excessive losses due to deep percolation at the upper ridges. Fine-textured soils with low infiltration rates require smaller streams to avoid excessive losses due to run-off at the downstream end and deep percolation at the lower reaches.

To obtain high efficiency in the surface methods of irrigation, the water distribution systems should be properly constructed to provide adequate control of water to the fields, and the land should be well prepared to permit the uniform distribution of water over the fields.

Flooding: in flood irrigation, the objective is to spread a thin layer of water over the surface of the land. Where water is applied from the field ditches without any ridges to guide its flow, or otherwise restrict its movement, the method is known as 'wild' flooding. Where water is brought to the field in permanent supply ditches and distributed from ditches built across the field, the methods is known as 'controlled' flooding.

The flooding method of irrigation is suitable for:

* lands that have such irregular surfaces that the other surface irrigation methods are impractical
* fields that were not initially prepared for irrigation, or because of the low initial cost of preparing land for this method
* areas where irrigation water is abundant and inexpensive
* crops such as rice which require standing water during most parts of their growing season.

It is very difficult to apply water efficiently by flooding methods. The size of the stream used, the depth of water as it flows over the soil surface, and the rate of intake of water into the soil all influence application efficiency.

Check basin method: this is the simplest and most common method of irrigation. It consists of applying irrigation water to level areas enclosed by ridges. Fairly level fields are well graded and then divided by ridges into rectangular or square basins (Fig. 20) of from 3 × 2 m to 30 × 30 m, so that each has a nearly level surface. The size of the basins depends on the soil type and the head of stream available. A large stream of water (150–200 m³ per hour) is used to fill these basins quickly to the required depth. The water is retained in the basins and then slowly percolates into the soil.

When irrigating orchards, square basins may be used as for other crops, but when the plants are widely spaced, the ring method of basin irrigation may be used. The rings are circular basins formed around each tree. An advantage of the ring method is that the entire area is not flooded, thus obtaining high water use efficiency.

Check basin irrigation is suited to smooth, gentle and uniform
land slopes and for soils with moderate to slow infiltration rates. The method is especially well suited to irrigating grain and fodder crops in heavy soils where water is absorbed very slowly and is required to stand for a relatively long time to ensure adequate irrigation.

**Border strip method:** the well-levelled and graded land is divided into a number of long parallel strips called borders that are separated by low ridges (Fig. 21). Each border strip should be level and should have a uniform gentle slope in the direction of the water flow. Each border is irrigated by allowing the water to flow from the upper end of the border in a thin sheet. The water moves towards the lower end with a non-corrosive velocity and covers the entire width of the border. When the advancing water reaches the lower end, the stream is turned to the second strip. The water temporarily stored in the border moves down the strip and infiltrates the soil, thus completing the irrigation.

The size of the borders depends on the size of the stream and the percolation rate into the soil. The width of the strip is adjusted to the
size of the stream to be handled (this may be 500–800 m³ per hour) and is usually 5–20 metres. The length of the strip is determined by the percolation rate into the soil, and varies from 60 to 300 metres. The higher the percolation rate, the shorter should be the strip. The following strip lengths are suggested:

* sandy and sandy loam soils 60–120 m
* medium loam soils 100–180 m
* clay loam and clay soils 150–300 m.

This method of irrigation is more suitable for soils with moderately low to moderately high infiltration rates. It is usually not used on coarse sandy soils with very high infiltration rates. This method is suitable for irrigating close-growing crops such as wheat, barley and fodder crops. It is not suitable for rice, which requires standing water during the greater part of its growing season.

**Furrow method:** in all the above described irrigation methods, almost the entire land surface is wetted in each irrigation. When using furrows for irrigation, only a part of the surface (from one-half to one-fifth) is wetted, thus reducing evaporation losses. Nearly all row crops such as maize, sorghum, groundnuts, cotton, tobacco, potatoes and sugarcane are irrigated by the furrow method. Furrow irrigation is suitable for most soils except sandy soils that have a very high infiltration rate and provide poor lateral distribution of water between the furrow. Furrows are made between the crops rows and the crop is grown on the ridges.

Furrow irrigation consists of running a stream of water into furrows with a gentle slope (Fig. 22). Water infiltrates into the soil and spreads laterally to irrigate the areas between the furrows. In this method a small size of stream (6–10 m³ per hour) is used. Large water streams in the field ditch are simply divided equally into the appropriate number of furrows. The optimum length of the furrows

![Fig. 22 Furrow irrigation of a vegetable crop](image-url)
depends on the infiltration rate, steepness of slope, and size of the stream. In general, irrigation efficiency is higher in long furrows than in short ones. With furrow irrigation it is difficult to prevent some erosion. On steep slopes, the furrows should be laid out on the contour, i.e. across the slopes.

**Corrugation method:** this is a partial flooding method, as the water does not cover the entire field surface. The stream of water is guided to flow through small furrows called corrugations evenly spaced across the field. The water spreads laterally, saturating the area between the corrugations. The main difference between this and regular furrow irrigation is that more but smaller furrows are used and the crop rows are not necessarily related to the irrigation furrows. The corrugations are made after sowing but before germination has taken place. The corrugations are U-shaped or V-shaped channels (furrows) of about 6–10 cm deep, spaced 50–150 cm apart, running down the slope from field ditches, or preferably from portable gated pipes made of aluminium or from hosepipes, in either case with outlet tubes. These movable pipes make the method more efficient. The length of the corrugations varies from 40 to 120 m and the slope is usually 2–6%.

In this method a very small stream (1–2 m³ per hour per corrugation) is used and as a result it takes a long time (8–48 hour) for the water to flow from one end of the corrugation to the other. The entire soil surface is wetted slowly by the capillary movement of the water which flows in the corrugation. This method of wetting the soil minimizes the crusting effect on the surface soil, which may be a problem when the entire surface is flooded.

Corrugations are usually made after the crops are sown and are suited to close-growing crops and for pasture growing on steep slopes. It is most suitable for fine- to moderately coarse-textured soils. It is not recommended for saline soils or when the irrigation water has a high salt content.

The advantage of this method is that it makes it possible to irrigate on relatively steep slopes without causing erosion, but the method is very conducive to increasing salinity.

**Overhead irrigation**

**Sprinkler irrigation:** in this method the irrigation water is applied to the crop above the ground surface in the form of spray. A sprinkler irrigation system consists of a pump to develop the desired operating pressure and main lines, laterals and risers to convey the water. Sprinkler heads or nozzles discharge the water in the form of spray. Rotating sprinkler heads, mounted on portable tubing, are the most widely-used type of overhead irrigation equipment.
Sprinkler irrigation is both technically and economically very suitable for terrain that is too steep or too uneven for surface irrigation, as well as for sandy soils. In this method, there is no need for the very expensive levelling of land.

This method can be used for nearly all crops (except for rice and jute) and on nearly all soils. It is not usually suitable for heavy clay soils where the infiltration rate is very low, less than about 4 mm per hour. Water should be applied only at such a rate that the complete precipitation is absorbed by the soil, resulting in no run-off.

There are many advantages to sprinkler irrigation. Soluble fertilizers, herbicides and fungicides can be applied to the irrigation water economically and with little extra equipment. It is used to protect crops against frost or high temperatures that reduce the quantity and quality of the produce. Water application can be more uniform and carried out with greater precision with the sprinkler system than with surface irrigation, except during times of high wind. Water-use efficiency is also greater with sprinkler irrigation. Sprinkling during the hot hours of the day may improve the microclimate, prevent transient wilting, increase stomatal opening and thereby improve the photosynthetic effectiveness. The elimination of the field ditches required for surface irrigation increases the net area available for crop production and reduces water losses to seepage and percolation. Furthermore, this method does not interfere with the movement of farm machinery.

On the negative side, the capital investment for equipment is relatively high. Water loss due to evaporation and the interception of water by the foliage is greater with sprinklers than with surface methods, but this can be reduced by night irrigation. It is not well suited to very windy areas, where sprinkling must be confined to certain hours of the day and night. For sprinkler irrigation, the water must be clean and free of sand, debris and large amounts of dissolved salts.

**Subsurface irrigation**

In subsurface irrigation, water is applied below the ground surface by maintaining an artificial water table at a predetermined depth, depending upon the soil texture and rooting depth of the plant roots. Water reaches the plant roots through capillary action. This is possible where there is a high permanent water-table or a relatively impermeable soil-stratum not too far from the soil surface. Water may be introduced either through correctly spaced open ditches in the field or underground pipelines such as tile drains or mole drains. The depth of open ditches or trenches varies from 30–100 cm and they are spaced about 15–30 m apart. The water application
system consists of field supply channels, ditches or trenches suitably spaced to cover the field adequately and drainage ditches for the disposal of excess water.

This method can be used for soils with a low water-holding capacity and a high infiltration rate where surface methods cannot be used and sprinkler irrigation is expensive.

Subsurface irrigation tends to cause salt accumulation in the root zone and can therefore be used only where the soil is regularly leached by rainfall, the irrigation ditches then serving as a drainage system.

**Drip irrigation**
In drip or trickle irrigation, water is applied to the soil at a very slow rate, drop by drop. In this method, plastic pipes are placed on the ground, along the row crops to be irrigated. In the pipe, at distances of one metre apart, are calibrated orifices from which water trickles at the rate of 2–10 litres per hour per orifice. At this slow rate of application, water percolates immediately downwards and sideways into the soil. It is a method of watering plants frequently and with a volume of water approaching the consumptive use of the plants, thereby minimizing such conventional losses as deep percolation, run-off and soil water evaporation.

This method is especially suited to arid areas with poor quality water, and areas with water scarcity and salt problems. When commercial crops such as vegetables and fruits have high return values, the practice of drip irrigation is more advantageous in raising these crops because of the resulting improvement in the quality and quantity of the yields. There is considerable saving in water by adopting this method since the water can be applied almost precisely to the root zone and there is no need to wet the entire area between tree crops. Like sprinkler irrigation, it permits the application of fertilizers through the system. The initial high cost is a disadvantage of this method.

**Efficient Water Management**
The important aspects of a comprehensive irrigation development programme are:

* integrated development of water resources
* efficient methods of conveyance and distribution of water
* judicious methods of water application
* proper soil management practices
* cropping pattern for high water-use efficiency
* proper timing of irrigation based on the developmental stages of the plant
* removal of excess water.
Integrated development of water resources
Watershed management and water harvesting are important aspects of a water resources development programme. It is necessary to treat watersheds to increase rainfall run-off. If low cost land is available in a watershed area, more land can be brought under where run-off can be increased by clearing and shaping the land. Run-off from small watersheds can also be increased by applying chemicals or other lining materials.

Loss of water by seepage and evaporation from farm tanks can be minimized by lining and covering reservoirs with plastic, artificial rubber or chemicals. Lining a farm tank can be done with a mixture of bentonite sodium carbonate.

Efficient methods of conveyance and distribution of water
For efficient water use, irrigation channels should be stable, have negligible scour and negligible deposition of sediments. To achieve this, irrigation channels and canals are lined with suitable materials which include concrete, rock masonry, brick, bentonite–earth mixtures, natural clays of low permeability, and various rubber, plastic and asphalt compounds.

If canals and channels are not lined, or not properly lined, weeds and willows will grow on the canal banks, and moss and other aquatic plants will grow in the canals. These greatly retard water velocity and so decrease canal capacity. Silt and clay sedimentation in canals also restricts water flow.

Judicious methods of water application
Whatever the method of irrigation, the essential requirement in water use is the application of the right amount of water and its uniform distribution in the field so as to wet the root zone to its storage capacity. The depth of water applied in each irrigation is a dominant factor influencing the efficiency of application; excessive depth of application would result in low efficiency.

Proper soil management practices
Soil management practices which relate to irrigation are land grading, land preparation and cultivation practices. These aim at obtaining a uniform distribution of irrigation water on the farm, storing large amounts of rainwater within the crop root-zone, and improving the soil structure for increased water availability.

Cropping pattern for high water-use efficiency
Cropping pattern means the way in which land and other resources, including irrigation, are used. An efficient cropping pattern must
ensure the most efficient use of land, fertilizer, irrigation water and other inputs. In the cropping pattern, the selection of crops and varieties is most important. A crop or variety should be short-duration, photo-insensitive, have a low water requirement, be fertilizer-responsive and high-yielding, all of which may enable the farmer to increase the intensity of cropping and thus raise the production per unit area and per unit input (irrigation, fertilizer, etc.).

_Proper timing of irrigation based on the developmental stages of the plant_

The subject has been dealt with earlier on in this chapter. Here only an example is given to show the importance of the timing of irrigation. For raising a good crop of rice, about 2,000 mm water is needed. Of this, 1,500 mm is lost by percolation during land preparation. This huge loss can be saved and the water used during the growing period of rice. The loss of water through percolation can be minimized by the incorporation of a small quantity of bentonite in the top 25 cm of soil.

_Reoval of excess water_

A large mass of land is water-logged due to seepage from canals. This land generally has a high production potential. There should be a proper drainage programme to drain out the excess water either into the canal or to a distant place to be used as irrigation water, but with proper salinity-checking devices.

_Irrigation Requirements of Important Crops_

_Rice_

Rice is a semi-aquatic plant and hence its water requirements (1,200 mm) are many times higher than most other food crops. The conditions under which rice is grown could broadly be grouped into two, namely lowland rice and upland rice. Lowland rice culture is a widely accepted practice for high production. In this practice, rice is generally transplanted on puddled soils and the land is held under submerged conditions by rain and/or irrigation water. The practice of puddling and land submergence, in general, has been found to reduce percolation losses, check weed growth, increase the availability of plant nutrients, regulate soil and water temperatures, favour the fixation of atmospheric nitrogen in the soil through algal growth, and improve photosynthesis in the lower leaves due to light reflected from the water surface.

The practice of keeping the soil at a shallow depth of submergence (about 5±2 cm water) throughout the crop growth period
is conducive to higher yields. The practice of shallow submergence directly saves a considerable amount of water compared to deep submergence. The practice of continuous shallow submergence is, however, possible only when the water supplies are adequate and assured. Experimental results are also available to show that it is not always necessary to follow the practice of continuous submergence, especially during the wet (rainy) season when humidity is high and evaporative demands are low. Under these conditions, the practice of intermittent submergence, i.e. submergence during the critical stages of initial tillering and/or flowering and the maintenance of saturation to field capacity during the other stages, gives yields comparable to those obtained under continuous shallow submergence. The water supply, if limited, could safely be curtailed during the non-critical stages of crop growth, viz., tillering, grain formation and maturity.

When continuous land submergence is practised, it is necessary to drain the soil once or twice during the growth period, especially on poorly drained clayey soils with a percolation rate of less than 2.5 mm/day. This practice is beneficial in removing the toxic substances such as sulphides developed under submerged conditions and in supplying oxygen to the root system. The drainage period could last from three days in sandy soils to seven days in clay soils.

**Wheat**

The water requirement of wheat is about 400 mm. The most practical criterion commonly adopted for scheduling irrigation to wheat is the one based on the physiological growth stages critical in demand for water. In wheat, the different growth stages are crown root initiation (CRI), tillering, jointing, booting, flowering, milk and dough. When the water supply is not limited, irrigation may be given at the initiation of each of these stages but if the water supply is limited, it should be given only at the critical stages. It has been observed that the crown root initiation stage (20–25 days after sowing) is the most critical time for irrigation. Regardless of the depth of planting, the crown roots always develop at about 2 cm below the surface of the soil. If the soil around the crown is dry at the time of crown root initiation, crown roots do not develop properly and only a few tillers are produced. Irrigation at this stage therefore stimulates root development and tillering. Any delay in the first irrigation reduces the yield considerably. The second important critical stage is flowering, which takes place 80–85 days after sowing (if the variety is 130–150 days to maturity). Of the other growth stages, jointing and milk-ripe rank third, followed by the tillering stage, and then the dough-ripe stage. Irrigation is applied at the
initiation of the stage, so that moisture remains available during the entire or greater part of the stage in question.

In sandy soils and in areas where summer starts early, the practice of irrigation at the different growth stages may not be adequate as the number of irrigations required may be more than the number of growth stages.

**Maize**
Maize is essentially a warm and humid season crop, though in areas with a mild climate it can be grown throughout the year. Its water requirement varies with the type of soil and the season in which it is grown, but in general it is about 620 mm. During the rainy season, irrigation may be required whenever soil moisture falls below the desired level. The early vegetative stage (20–40 days after sowing) and the tasselling and silking stages (45–60 days after sowing) have been found to be the critical stages in the demand for water.

Maize is very sensitive to excess water and waterlogging. The submergence of the soil for 3–5 days during the seedling or flowering periods reduces the yield considerably. Adequate provisions for draining off excess water from the field should therefore be made. In areas of high rainfall, it is advisable to plant maize on ridges, or to make ridges when the plants are established.

**Sorghum**
The water requirement of sorghum is about 500 mm. Sorghum is grown on a variety of soils and takes 110–130 days to mature. When grown on clay to clay loams, the irrigation requirement is lower than when grown on sandy soils. The seedling, pre-flowering, flowering and grain formation stages, taking place at 2–4, 12–14, 14–16 and 17–18 weeks after sowing, respectively, have been found to be critical times for the water demand of sorghum.

**Millet**
The water requirement of millet is about 500 mm. Pearl or bulrush millet is a crop of warm areas of low rainfall. It is mostly grown in the rainy season under rain-fed conditions, and takes 80–90 days to mature. It has been observed that millet responds well to the application of supplemental irrigations (if needed). Experiments have shown that millet tolerates about 75% depletion of available moisture from 0–30 cm depth of soil on heavy clay soils, and 50% depletion in sandy soils. Irrigations may be given at these levels of available water.
Barley
The water requirement of barley is about 300 mm. In drier areas, the crop needs irrigation for good growth. The moisture-sensitive periods occur at the end of the shooting stage and during ear emergence. It has been observed that during these periods, drought conditions have their maximum effect in reducing yield and irrigation has the greatest effect in increasing yield.

Grain legumes
Grain legumes (pulses), by virtue of their deep tap root system, utilize soil moisture very efficiently and hence require few irrigations. Legumes grown in the rainy season are normally grown without any irrigation. Legumes grown in the dry (winter) season benefit from one or two irrigations. Most legumes do not require irrigation at the early vegetative stage, as this may do more harm than good by interfering with the nodulation and oxygen requirements of the roots at this time. Irrigation during the flowering and pod formation stages gives higher yields.

Oil-seed crops
Oil-seed crops are efficient in their water use and hence require less water for their growth than many other crops. They are mostly grown under rain-fed conditions, but their yields can be increased substantially if, during the flower and fruiting stages, irrigations are given at 50% available moisture level in the soil.

Cotton
Cotton is mostly grown in the rainy season. Normally no irrigation is required unless rainfall distribution is very erratic. The cotton plant has a deep and extensive root system which develops rapidly and within 70–80 days may extend to a depth of as much as 1.8 m and laterally to the same extent. Cotton can extract most of the soil moisture to the depth of rooting. This characteristic has a considerable influence on the irrigation requirements of cotton.

Sufficient water should be added to the soil, either from rainfall or irrigation, to ensure that the entire root zone is brought to field capacity early in the growing season (up to about 40 days after sowing). Irrigation may be needed at the pre-flowering stage if there is little or no rainfall at that time. It is desirable to maintain soil moisture at 50% availability in the upper 45–75 cm. If visible signs of moderate to severe stress are seen, such as dark colour of the leaves and late afternoon wilting symptoms, it is desirable to irrigate. During the flowering and boll-formation stages, extreme water
stress should be avoided. Irrigation after the flowering and fruit-setting periods is needed only to supply sufficient soil moisture for fibre and seed development.

**Sugarcane**

Sugarcane occupies the land for about 10–12 months and requires adequate irrigation to realize its potential yield. It has an extensive fibrous root system, with roots most extensive in the upper 60–90 cm of soil. In well-drained, deep loamy soils some roots may extend much deeper (about 240 cm). This extensive root system extracts moisture from the deepest layers, but moisture extraction is greatest in the upper 120 cm.

Optimum yields of sugarcane are obtained by maintaining a very high moisture level throughout the root zone, and during the entire growing season, until about one month before harvest. Just before harvest irrigation may be stopped or reduced, as this results in the accumulation of sucrose in the cane. Irrigation should be scheduled on soil moisture content in the top 60 cm soil depth. The moisture content should be kept at 60% of total available moisture.

**DRAINAGE**

The successful cultivation of economic crops largely depends upon the adequate drainage of the land in which they are grown. Drainage may be defined as the means by which soil and subsoil water is controlled in, and removed from, the root zone in relation to the health and vigour of the crop.

Although the extension of irrigation facilities is a sign of the prosperity of a nation, it also has its negative sides. Irrigation can convert agriculturally productive land into waterlogged land and create a salinity problem. These two problems are caused by the storage of excess water in the soil, causing a rise in the water table. Sometimes the rise is so high that the water table actually reaches very close to the surface.

The major sources of excess water that make drainage necessary on parts of irrigated land are

* seepage losses from reservoirs or canals
* deep percolation loss from irrigated lands
* flooding of low lands
* flow of groundwater towards waterlogged lands in the arid region.

The basic aim of field drainage is to assist land to get rid of water from the upper layers of the soil in a manner that will maintain the conditions which provide aeration, warmth and adequate moisture
within the root zone of the crop. The adequate drainage of crop-producing lands requires a general lowering of shallow water tables. Drainage is a necessity in both humid and arid regions. In arid regions, irrigation and drainage are complementary practices.

The water table can be lowered by

* eliminating or controlling sources of excess water
* improving natural drainage facilities
* providing man-made artificial drainage systems, such as open channel drains, covered clay or concrete pipes and pumping ground water.

**Field Drainage Systems**

Field drainage systems comprise surface and underground drainage systems. Underground drainage includes mole and tile drains.

**Surface drainage**

Open drains are largely used to convey water to distant outlets. This system is practised on land with pervious soil and free-draining subsoil. Deep drains are made at the lower edges of fields, which are interconnected with a system falling gently to a main outlet. Sometimes it is desirable to put in a few widely spaced supplementary surface channels in the field, leading to the head drains or to the tile drains at wide intervals. The depth of open drains ranges from 2–4 m. Naturally free-draining soils usually present no difficulty with irrigation, as few or no drains are needed in the fields.

**Underground drainage**

Mole drains are cut in the soil at a pre-arranged depth, below the main root zone. This method can be used to advantage where the soil texture is such that the drain will not easily collapse. A high proportion of clay in the subsoil is a desirable feature. Mole drains are usually 10–15 cm in diameter, circular or nearly so in cross section, 50–60 cm deep, and 3–4 m apart. Some cuts are made in the drains. These cuts assist the passage of water from the surface and through the soil to the drains. Mole drains require not only suitable land but proper grading of the drains and free outlets at the lower ends, leading into surface cuts of sufficient depth which discharge to main drainage canals or a natural water course. In favourable circumstances, mole drains give efficient service over many years.

Tile drains are formed by hollow cylindrical tiles of 10–25 cm internal diameter. The tiles are made of concrete (a mixture of cement and sand in the ratio of 1:6). The tile drains are laid in deep trenches cut at predetermined intervals to a depth of 75 cm or more,
with a slight fall towards the outfall end. The distance between the drains may range from 9–72 m, depending on the nature of the soil, the rainfall and the depth at which the drains are laid. In heavier soils, shorter distances are maintained. In trenches made by machine, the tiles are laid regularly end to end at the bottom of the trench without fixing them with solid joints. Water flows from the saturated soils into the tile through the pipe joints, not through the walls of the concrete pipe. To facilitate the flow, it is wise to place a strip of tar paper over the joints and a screened-gravel envelope of about 7 cm thick around the pipe so that the soil material does not enter the pipe. The gravel is placed around the tile drains and then the trench is filled with earth. The successful operation of tile drains depends upon the movement of water downwards through the soil to the drain and the presence of small unobstructed spaces between the hollow tiles, which are so laid as to form a continuous channel with a uniform gradient leading to a free outfall in a main drainage canal or natural water course.

**Advantages of underground drainage**

Surface drains are troublesome to maintain and water distribution interferes with them, the converse being true also. With underground drainage these problems do not arise. Other advantages of underground drains are the low maintenance costs and the unobstructed passage of implements over them. Arable land is not sacrificed as is often the case with surface drainage. Underground drainage systems are especially suited for irrigated lands with free-draining soils and satisfactory outfalls for the field drains. Apart from their main functions, they also indirectly help in providing water for irrigation. The water which is discharged from the underground drains into the main drainage canal can be lifted and used for irrigation. Underground drainage also assists in protecting the soil from erosion. The finer particles of surface soil carried away in large quantities and deposited in the trenches and main drains can be returned to the surface when the drains are cleaned and reformed after some years.

**Benefits of Drainage**

Adequate drainage improves soil structure and increases and perpetuates the productivity of soils. According to Israelson and Hansen (1962), drainage benefits agriculture by:

* facilitating early ploughing and planting
* lengthening the crop-growing season
* providing more available soil moisture and plant food by increasing the depth of the root zone soil
* helping in soil aeration
* decreasing soil erosion by increasing water infiltration into soils
* favouring the growth of soil micro-organisms
* leaching excess salts from the soil
* assuring higher soil temperatures.

**Maintenance of Drains**
The maintenance of drainage systems requires the regular removal of soil and vegetation from the drains. In open drains, silt and clay sedimentation and the growth of weeds and willows restrict the water flow. Silt and clay sediments can be removed from the drains with the help of an excavator. The weeds and willows can be controlled with chemicals. This is necessary because they extend their root systems deep enough to obtain water. The roots enter the joints of closed drains and continue to grow inside the pipe and obstruct the flow of drainage water. Because of this obstruction, soil particles begin to settle in the pipe, gradually sealing the drains. To keep closed drains clean, it is essential to destroy the penetrating roots periodically by adding some chemicals to the drain water. To achieve this, all undesirable vegetation in the field should be killed by chemicals.
is being farmed, natural vegetation (bush fallow) is allowed to grow on the old site. Eventually, after several years of bush fallow, the farmer returns to the original location. In its original and more primitive form, shifting cultivation involved moving the home along with the farm, but this form of shifting cultivation exists in only a few places in the world today. On the other hand, shifting cultivation in which the farm is moved while the home is stationary is a common practice today in most parts of the tropics, including tropical Africa.

The details of the practice of shifting cultivation vary from place to place, but some common features can be outlined. The farmer first selects a site which has been under bush fallow for several years. The vegetation on the land is then cleared, using hand tools such as axes and machetes. This clearing is done during the dry months preceding the planting season. The plant debris is allowed to dry for a few weeks and is then set on fire. Any remaining unburned material is either left on the field, or is gathered together and burned again. Crops are then grown on the field for one, two or three years, starting with crops with high fertility requirements and ending with crops whose fertility requirements are low.

Shifting cultivation as practised in the tropics is invariably linked with low levels of inputs of technology and management. Most of the operations are carried out with simple hand tools, and the labour requirements are high. Unfortunately, the very nature of shifting cultivators tends to discourage a high level of inputs. Because the farm stays in one location only a short time, there is no incentive to invest in permanent structures such as storage sheds and irrigation facilities. Even certain pest control or soil conservation measures which may have long-term benefits will only be carried out with reluctance on a field that is soon to be abandoned. Moreover, the farms are usually at locations which are inaccessible to most farm machinery. Consequently, shifting cultivation continues to be characterized by a low level of technology and correspondingly low yields.

To the shifting cultivator, bush-burning constitutes a technologically easy answer to the problem of clearing plant debris from the field prior to cropping. However, the practice of bush-burning has certain serious adverse consequences. Most of the nutrient nitrogen and sulphur present in the debris are converted to oxides during burning, and lost to the atmosphere. In addition, burning may destroy beneficial micro-organisms and have adverse effects on soil structure. On the other hand, burning may also be of some benefit. As already indicated, it is an easy and inexpensive way of getting rid of excessive plant debris. Secondly, it may serve to kill
pests, pathogens and weed seeds which may be present in the soil. Finally, the alkaline ash left on the soil after burning serves as a good soil amendment in most locations of the humid tropics, which, because of high rainfall and leaching, have acid soils. Indeed many indigenous cropping systems in the tropics have evolved to place a very high premium on the ash. In the 'chiameno' system practised in parts of Zambia and the Congo basin, for example, a deliberate attempt is made to increase the quantity of ash by bringing in vegetation from outside the intended cropping area to be burned on the intended area. Apart from its effects on soil acidity, the ash also serves as an immediate source of certain mineral nutrients such as K and Ca for the planted crops. If it were not for the burning, such nutrients would have remained tied up in undecomposed vegetation for several more months.

It appears that shifting cultivation has evolved in traditional agriculture to cope with the problem of decreasing soil fertility during cropping. Virgin land, or land that has been recently cleared from bush fallow is of relatively high fertility. However, as cropping continues, the fertility of the land decreases with time. By the third or fourth year, soil fertility has become too low to support economical crop production, and the yields obtained are low. Allowing the land to revert to bush fallow allows the fertility of the soil to build up again. The longer the duration of the bush fallow, the higher the level of restoration of soil fertility. In times and places where land is available, the bush fallow lasts for ten years or more. However, the increasing scarcity of land often forces farmers to return to the same site after a bush-fallow period of only three or four years. In such cases, soil fertility is not fully restored before the onset of cropping and supplementary fertilizer applications might be required in order to obtain reasonable yields.

In view of the fact that the land is most fertile at the end of the bush fallow period, most shifting cultivators plant their most nutrient-demanding crops such as yams in the first season after bush-burning, while crops such as cassava which can tolerate less fertility are planted in the second or third season, just before the land is reverted to bush fallow. It should be mentioned that factors other than declining soil fertility may sometimes influence the decision on when the land should be reverted to bush fallow. An unusually high incidence of diseases and pests may precipitate the decision to abandon the site in preference for new ground. Factors associated with social or religious customs may dictate the abandonment of a site before its fertility level has become marginal.

One obvious aspect of shifting cultivation is that it requires a great deal of land to maintain the system. Even though each farmer, at any
given time, is cultivating one field (or sometimes two), he at the same time keeps several equivalent fields under various stages of bush fallow. As such, only a small fraction of the total available land is under active cultivation at any time. An attempt to increase this fraction by shortening the bush-fallow period will mean cultivating soils whose fertility and yield potential are relatively low. It is mainly because of this large land requirement that shifting cultivation tends to break down in the face of increasing population pressure on land. When the pressure becomes too great, shifting cultivation is abandoned completely in favour of continuous cropping on the same piece of land. This has been the trend in many parts of the tropics, and this trend is expected to continue.

In addition to its low efficiency of land utilization, shifting cultivation also has a low efficiency of labour utilization. Apart from the low level of inputs and mechanization already mentioned, there is also the fact that new land has to be cleared from bush practically every year. Such land clearing is relatively tedious, and in the humid tropics where bush growth is rapid, it can constitute a significant percentage of the labour expended on cropping each year.

CONTINUOUS CROPPING

In contrast to shifting cultivation, continuous cropping implies the cultivation of the same piece of land year after year. Fallowing may occur, but it never occurs for more than a season or two. The absence of a protracted fallow period means that other soil management procedures must be used to maintain high soil fertility. Partly for this reason, continuous cropping is usually associated with a higher level of technology and management than is found in shifting cultivation.

As continuous cropping entails that the land will be used for cropping on a long-term basis, it is often expedient and economical to carry out various operations of long-term value on the land after clearing. One such operation is the removal of tree stumps and woody roots from the field. This operation is imperative if mechanical tillage devices (ploughs, harrows and ridgers) are to be used with ease on the field. It is an extremely tedious operation, but the farmer can take consolation from the fact that once the operation has been carried out, its benefits can continue to be enjoyed over several years of continuous cropping. Other kinds of operations that may be carried out prior to planting include the construction of contour bunds for erosion control, and the grading of land for irrigation purposes. Each of these is a valuable long-term investment under continuous cropping.
With the absence of bush fallow, it might be wondered how soil fertility can be maintained under continuous cropping. This is done in at least three ways. The first is that continuous cropping does not rely solely on the native fertility of the soil. Fertilizers and other soil amendments are applied to the soil at various times in order to boost fertility. These fertilizers may range from natural organic products such as manures and compost, to artificially produced chemical fertilizers. A second way in which soil fertility is maintained under continuous cropping is by the judicious selection of the crops and crop combinations to be grown. In this respect, crop rotations and carefully planned intercrop combinations are indispensable. These practices ensure that nutrient removal from the soil is relatively uniform, and that soil nitrogen is occasionally replenished by the cultivation of legume crops. A third soil fertility conservation measure practised in continuous cropping is that of introducing short-term fallow periods into the cropping cycle. After every three or four years of continuous cropping, the land is allowed to lie fallow. This fallow period, however, does not last for several years as with bush fallow, it usually lasts for only a few months. Furthermore, the land under fallow in a continuous cropping system is not simply abandoned. A leguminous cover crop may be planted on the land and allowed to grow on it for the duration of the fallow. Sometimes the cover crop can be used for forage (e.g. Centrosema) so that harvesting of the forage occurs at the end of the fallow, just before normal cropping resumes. In such a situation, the fallow period, rather than being a period when no crop is growing on the field, is a period when a less intensive crop is allowed to grow on the field. Whether a cover crop is grown on the field during the fallow, or whether the field is left to natural vegetation, it is usual to incorporate the plant material into the soil at the end of the fallow period. In this way, it provides green manure for the crops growing after the fallow.

One major objective of fallowing, therefore, is the improvement of soil fertility through the fixation of nitrogen by legumes during the fallow, and through increasing the soil's organic matter content when the fallow crop or vegetation is ploughed under. Soil structure is also improved since the soil is worked only sparingly during the fallow period, and the cover crop protects the soil from erosion.

The practice of continuous cropping is therefore based on the judicious management and conservation of the soil. Without these, soil fertility soon becomes depleted and crop yields are adversely affected.

Land utilization under continuous cropping is extremely efficient. A very high percentage of the land is under crops at any given
time. Even the remaining land under fallow can be made to give economic returns, as when a forage crop is grown on the fallow land. Another aspect of efficiency in continuous cropping is that it is possible and economically feasible to erect permanent structures on the farm site. Good access roads, irrigation facilities and storehouses can be built in the expectation of their being used for many years.

**CROP ROTATION AND MONOCULTURE**

In the practice of continuous cropping, it is theoretically possible to grow the same crop on the same land season after season. Such a practice is referred to as monoculture. Alternatively, the farmer may plan a definite sequence for growing his crops on the land. The practice of growing different crops, one at a time, in a definite sequence on the same piece of land is referred to as crop rotation. The design of a good crop rotation is by no means an easy task. The farmer must decide what crops to have in the rotation, in what sequence the crops should occur, and for how many years or seasons each cycle of the rotation must run.

Economic considerations are a major factor in deciding on what crops to have in the rotation. Usually there is one main crop (sometimes two) which is the farmer’s primary target, and around which he builds the rotation. He may therefore design his rotation so as to obtain the maximum yields of the target crop, while tolerating whatever yields may result from the other crops. This sort of situation is found where the target crop is the main cash yielder (e.g. tobacco in a tobacco-growing district), while the other crops in the rotation are grown mainly for food. Alternatively, the rotation may be designed to maximize the total economic yield from all crops in the cycle, without giving particular favour to one crop.

Invariably, a legume crop is included in the rotation, whether or not it is the target crop. It is included because of its ability to build up the nitrogen status of the soil through nitrogen fixation in its root nodules. The exact legume chosen depends on its ability to yield well in the area and to command a good price. A fallow period is sometimes also included in the rotation although, as mentioned earlier, a forage or green manure crop may be grown on the field during the fallow.

Several factors have to be considered in deciding the sequence of crops. Usually the target crop comes immediately after the legume or the fallow period. At this time the fertility of the soil is at its peak and the best realizable yields of the target crop can be expected. Crops which are known to have a high demand for nutrients are also timed for the first or second season after the fallow.
Another principle involved in planning the crop sequence is that crops which are deep feeders should alternate with shallow feeders. In this way, nutrient removal occurs uniformly from the various soil layers rather than occurring in only one layer.

Furthermore, the crop sequence is influenced by disease and pest (including weeds) consideratons. Crops that are botanically similar (such as tomatoes and potatoes) are likely to be attacked by the same diseases and pests, and should not normally follow each other in the rotation. Even dissimilar crops which are known to suffer from the same diseases or pests, should not follow each other in the rotation, unless those particular diseases or pests are absent from the area. Yams, for example, should not follow cowpeas in rotation if the root-knot nematode is prevalent, as the nematodes left over from the cowpea crop will severely reduce yam yields. However, if the nematode problem does not exist in the area, yams could conveniently follow cowpeas.

The number of years for which each cycle of the rotation should run is determined by the number of crops in the rotation, the length of their growing seasons and how frequently the farmer can grow the target crop without running into problems of disease and soil fertility. For example, the time interval between the harvesting of the target crop and its being planted again on the same piece of land should be long enough to prevent the carry-over of pathogens in crop residues from one cycle to the next. In practice, each cycle of the rotation may last from 3–8 years, sometimes with one crop occurring more than once in each cycle such as in the Egyptian cotton rotation shown in Table 6.

<table>
<thead>
<tr>
<th>Year</th>
<th>Winter</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Clover</td>
<td>Clover</td>
<td>Wheat</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cotton</td>
<td>Maize</td>
<td>Rice</td>
<td></td>
</tr>
</tbody>
</table>

In planning his rotation, the farmer may consider his entire field as one plot. He then rotates the crops in sequence on the field. At any given time, there is only one crop on the field, and that crop will not return again until the next cycle some years later. This system, however, has three main disadvantages:

* the growing of one crop means that the demand for labour occurs in peaks. Labour demand is more evenly spread if many crops are grown simultaneously.
the risk of crop failure is ever-present, and the risk is greater where only one crop is grown than where many crops are grown since each crop occurs on the farm only once every several years, specialized facilities for particular crops, such as processing facilities for the target crop, can only be utilized once in several years, a situation that is definitely inefficient.

For the above reasons, most farmers who practise crop rotation find it more convenient to divide their field into as many plots as there are years in the rotation. The farmer then starts with a different crop on each plot and progresses through the rotation. In this scheme, all the crops are present on the farm at any given time. Looked at in another way, each plot passes through the same sequence of crops but is at different stages of the rotation cycle from the others. An example of such a rotation is given in Table 7.

Table 7  Example of a 3-year crop rotation found in the Guinea savanna region of West Africa

<table>
<thead>
<tr>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plot A</td>
<td>Cotton</td>
<td>Guinea corn</td>
</tr>
<tr>
<td>Plot B</td>
<td>Guinea corn</td>
<td>Groundnuts</td>
</tr>
<tr>
<td>Plot C</td>
<td>Groundnuts</td>
<td>Cotton</td>
</tr>
</tbody>
</table>

The main advantages of crop rotation are probably obvious from the foregoing discussion. It is an effective means for controlling diseases and pests. In monoculture, for example, diseases and pests of the particular crop always have their host around, and therefore have the opportunity to build up over the years. In crop rotation, however, the pathogens and pests of a particular crop are more likely to die off when their host crop is followed by a completely different non-host crop.

Secondly, crop rotation is a device for maintaining high soil productivity over several years of continuous cropping. The inclusion of legumes and fallow in the cycle, and the use of crops that feed at different levels are devices to sustain soil productivity. Monoculture does not provide these devices.

Thirdly, the type of crop rotation where the field is divided into several plots, offers the farmer some insurance against crop failure, and enables him to spread out his labour needs.

The practice of monoculture is relatively less common than that of crop rotation. It can be found, for example, in sugarcane farming around Bacita, Nigeria; in sisal production in East Africa; and in taro production in Hawaii. In these cases, a relatively high level of technology is employed in the crop production, and it is possible to
compensate for some of the potential disadvantages of monoculture. An example of monoculture practised at the technological level of the traditional farmer is the incessant cultivation of yams along the flood banks of the lower Niger river in the Ogbaru district of Nigeria. In this case, the annual flooding of the fields by the river just after harvest serves to replenish soil fertility and probably also to control weeds and diseases.

Where it can be effectively practised, the main advantage of monoculture is that it permits the maximum concentration of production effort on a single target crop.

**INTERCROPPING AND SOLE CROPPING**

The practice of growing one crop variety alone in pure stands on a field is referred to as sole cropping. In this practice, only one crop variety occupies the land at any one time. The alternative practice of growing two or more crops simultaneously on the same field is called intercropping. The various crops in the intercrop do not necessarily have to be sown or harvested at the same time; the main requirement is that they are on the field at the same time for a significant part of their growing periods.

There are various kinds of intercropping systems based on the exact spatial arrangement of crops on the field. When the various crops are grown in separate rows, it is called row intercropping. When each of the various crops on the field is grown in several small patches interspersed with similar patches of the other crops, the situation is referred to as patch intercropping. When the various crops are grown intermingled more or less at random with each other, it is referred to as mixed intercropping.

One further situation which has not been covered by the above definitions occurs when a second crop variety is sown between the stands of an existing sole crop just before the first crop is harvested. As such, both the first and the second crops spend most of their field lives as sole crops, and grow together on the field for only a brief period. This situation has sometimes been referred to as relay intercropping, although it could also be seen as a case of overlapping crop rotation.

When ridges or mounds have been made, the spatial arrangement of the various crops may be determined by the particular needs of each crop. In the Abakaliki area of Nigeria, for example, intercropping is practised, but the mixing of crops on the field is not necessarily at random (Okigbo, 1978). Yams, which require a deep layer of tilled soil, are planted at the top of the mounds, while rice, because of its high moisture requirement, is planted in the lower ground between the mounds. Other crops such as maize, pumpkins
and melons are planted at intermediate positions between the rice and the yams.

Apart from deciding what crops to grow and their spatial arrangement on the field, the intercropper must also decide the exact proportions of the various plants on the field. An intercrop of maize, cowpeas and melons could, for example, have an infinite array of proportions in which the separate crops occur on the field. The situation in which there are equal stands of each crop is only one of several possible situations. The decision on the proportions of the crops is to some extent influenced by which crop (or crops) the farmer considers his main crop, and which ones he regards as subsidiary. Indeed, in young plantations of perennial crops, the main crop (the perennial crop) is planted at the density recommended for it and the farmer simply grows as much of other intercrops between the young trees as space will allow. As the trees get bigger in subsequent years, the amount of space between them decreases, so that the relative proportion of the subsidiary crop also decreases.

Another factor in deciding the proportion of the component crops is the nature of the crops themselves. A few stands of pumpkin or melon occupy a lot of land and have a high economic yield, whereas rice stands, for example, would have to be much more numerous to be meaningful.

The evaluation of yield from an intercropping situation is much more complex than in sole cropping. The harvested yield of one crop make very little sense if added arithmetically to the harvested yield of another crop. In order to solve this problem, the concept of relative yield has been evolved. The relative yield of each component crop in an intercropping situation is the yield of that component in the intercropping situation divided by what that crop would have yielded as a sole crop, covering the same area as the intercrop and managed at the same level. Suppose, for example, that a field with a crop combination of maize and cowpeas yields 1.5 tonnes/ha of maize and 0.25 tonnes/ha of cowpeas. If the expected sole crop yield of maize is 2.0 tonnes/ha and that of cowpeas is 0.50 tonnes/ha, then the relative yield of maize is 1.5/2.0 = 0.75 and the relative yield of cowpeas is 0.25/0.50 = 0.50.

The sum of the relative yields of the various component crops in the intercrop is sometimes called the relative yield total. A little reflection will show that this sum is also an indication of how many times the land area used for the intercrop would be required to produce the same yields of the component crops when they are grown as sole crops. The relative yield total is therefore more conventionally referred to as the land equivalent ratio (LER).
Mathematically:

\[
LER = \frac{\text{intercrop yield of crop A}}{\text{sole crop yield of crop A}} + \frac{\text{intercrop yield of crop B}}{\text{sole crop yield of crop B}} + \frac{\text{intercrop yield of crop}^a}{\text{sole crop yield of crop}^a}
\]

= relative yield crop A + relative yield crop B + relative yield crop\textsuperscript{a}

In the maize/cowpea combination considered above, the \( LER = 0.75 + 0.50 = 1.25 \). An \( LER \) greater than 1.0 implies that for that particular crop combination, intercropping yielded more than growing the same number of stands of each crop as sole crops. An \( LER \) of less than 1.0 implies that the intercropping was less beneficial than sole cropping.

Even though the \( LER \) is the most widespread criterion for comparing intercrop and sole crop yields, it is by no means the only one. Some workers calculate the monetary value of the yield obtained from the various intercrop and sole crop situations and make comparisons on this basis. Others have made calculations on the total quantity of calories or energy represented by the yields in various situations and compared the values to determine which arrangement was most beneficial.

It has been found that in carefully planned intercropping situations, the \( LER \) is usually greater than one. This means that there is a yield advantage in growing crops together rather than growing each one separately. This is perhaps the most significant advantage of intercropping. This advantage may arise from several sources. Firstly, the crops may complement one another in their use of field time. The periods of their peak demands for light, water, nutrients and other resources may differ, so that in general there is a more efficient utilization of the resources available. For example, during the two or three months that yams take to sprout and establish adequately on the field, a quick intercrop of maize or melon would beneficially utilize the field resources during this time.

Secondly, the component crops of an intercrop may complement each other in their use of space. For example, an intercrop of a deep-rooted and shallow-rooted crops can exploit various horizons of the soil; when grown separately as sole crops, each component crop would only be able to exploit its own specific rooting horizon. Thirdly, an intercrop may be able to utilize resources which the main crop may not be able to utilize or which may even be disadvantageous to it. On hydromorphic soils, for example, yams can be grown on the mounds or ridges, but not in the intervening lower
ground. A rice intercrop adequately exploits the waterlogged lower areas. Similarly, a shade-tolerant species such as the tannia cocoyam growing under a full canopy of oil palms is able to utilize some of the transmitted light which would otherwise have been wasted, thereby increasing the efficiency of light utilization. Fourthly, certain crops may exert specific beneficial effects on others. For example, plantains intercropped with young cocoa seedlings are used to provide shade for the delicate seedlings (Fig. 23). Similarly, in an intercrop of a legume with a cereal crop, the cereal is expected to benefit from the nitrogen fixed by the legume.

It is often stated that one of the advantages of intercropping is that by having many crops on the land simultaneously, the farmer is more or less buffered against failure of one of the crops, but this same advantage could equally be derived by dividing the fields into large plots and sole cropping each plot in rotation. It is therefore not truly an advantage of intercropping per se. A similar comment can be made about the fact that intercropping allows for a more uniform labour distribution throughout the year.

It has been further suggested that when one component of an intercrop combination fails, the other components of the combination are able to utilize the resources that would have been available to the failed crop, and so yield better than they would have done otherwise. As such, the collective yield from the crops is not much depressed. Yield stability is therefore one of the advantages of intercropping. This factor is in addition to, and distinct from, the advantage of the higher yields that result from intercropping in normal years. It should be mentioned, however, that in sole cropping the farmer reserves the option of ploughing under the failed crop and perhaps planting a quick short-season catch crop in order to cut his losses. This option does not exist in intercropping where only one of several component crops may have failed.

Another major advantage of intercropping is that the spread of diseases and pests in considerably less rapid than in sole cropping. This is probably because the mean distances between the plants of the same component crop are greater. In many instances, the other component crops are not susceptible to the particular disease or pest afflicting one component. Indeed, the other component crops growing between the plants of one component may act as physical barriers to the spread of diseases and pests.

For all its advantages, intercropping has some serious disadvantages. Most of these are associated with the fact that since many crops exist together on the field, it is not possible to tailor production practices to the needs of any particular crop. Pest and disease control is particularly difficult because pesticides which have been
Fig. 23  Plantains used as shade for young cocoa plants in the field

evolved to control a disease on one component crop may have deleterious effects on other crops in the combination. Worse still, operations such as planting and harvesting are difficult to carry out by hand, and just as difficult to mechanize. This is partly because, for at least some of the component crops, planting and harvesting
must occur at a time when there are other live component crops on
the field.

It has been suggested (Nangju, 1975) that mechanization may be
easier in intercropping if there are only two or three components
crops, if planting is done on the flat or ridges, if the crops are planted
in straight rows (perhaps row-intercropping) and if all component
crops are planted at the same time. Even if these modifications can
be implemented, the difficulty of mechanization will still remain
one of the serious drawbacks of intercropping.

In sum, therefore, intercropping appears not to be amenable to
many of the modern technologies now available to the agriculturalist. Yet, the majority of farmers in the tropics practise the system.
Research into intercropping has been intensified at various tropical
agricultural research institutes during the past few years. This
research aims at selecting varieties that perform well under intercropping; identifying compatible crop combinations that will, together, give high yields; and developing appropriate cultural and
mechanical technologies for intercropping. When this research begins to bear fruit, it may be possible to lift the practice of intercropping from its present lowly laborious state.

CROPPING SYSTEMS IN AFRICA
In most parts of tropical Africa, shifting cultivation with intercropping is the predominant practice among traditional farmers. Most of
these farmers concentrate on the production of food crops such as
maize, yams, rice, cassava and guinea corn. Sole cropping (with
crop rotation) of arable crops is uncommon, except among the
large-scale farmers in East and southern Africa, and in the irrigated
agriculture of the Nile valley in Egypt. A few government-sponsored
farms in various countries also grow food crops on large hectarages
and practise sole cropping with crop rotation. In each of these cases,
continuous cropping is the rule rather than shifting cultivation.

In tropical Africa, plantation and cash crops are invariably grown
as sole crops, such as oil palms in Cameroon, coffee in Kenya, cocoa
in Ghana, and rubber in Nigeria. In some instances, they may be
intercropped with food crops when the plantation is young, such as
plantains and cocoyams in cocoa plantations and cassava in rubber
plantations. The level of technology employed on these farms is
usually higher than that for the food crop farming in which most of
the population is engaged. Even for arable cash crops such as
tobacco and groundnuts in Nigeria, sole cropping is the rule, but the
sole crop may be subjected to shifting cultivation, or to continuous
cropping with rotation.
In nearly all parts of tropical Africa, the practice of shifting cultivation entails that the farm may be at a considerable distance from the home. As such, the practice of keeping a second farm (home garden) in the back yard is common. Continuous cropping with intercropping is the rule on such farms. Quite frequently the fertility of these back yard farms is boosted with household refuse and manure from domestic animals.

The cropping systems pertaining to the specific crops in tropical Africa will be discussed in Part Two.
CROP ESTABLISHMENT PRACTICES

SITE SELECTION
When embarking on crop production, one of the earliest decisions that must be taken is where to locate the farm. There are two slightly different aspects to this decision. The first is deciding where in the country or region the farm should be located. After deciding in which part of the country to locate the farm, the second aspect of the decision is selecting the exact piece of land to be used for the farm.

Deciding in which part of the country to establish the farm is guided by several factors. The climatic requirements (rainfall, temperature, etc.) of the main crops envisaged for the farm would determine the most appropriate part of the country. A farmer proposing to grow potatoes in Nigeria, for example, should know that he should seek a site in the Jos Plateau or the Mambilla Plateau. Similarly, a farmer interested in establishing a rubber farm in Cameroon, will concentrate his attention on the warm, rainy south-western part of the country.

Nearness to markets or to processing facilities is another factor in deciding the regional location of a farm. This is particularly true of bulky crops, perishable crops, or crops which require extensive processing after harvest. A good example in this respect is rice. Many small-scale rice farmers cannot afford adequate processing facilities for their harvested produce. If such a farmer is located in an isolated region without processing facilities, he is at a definite disadvantage in comparison with other farmers located closer to processing facilities. As will be seen later, this factor is also important in deciding the exact location of the farm.

The presence or absence of particular diseases and pests that attack the proposed crops is also a factor to be considered when deciding on the regional location of the farm. Even where the soil and climate favour the growth of a crop, it might be uneconomical to grow that crop if diseases and pests are numerous. A good example
is cowpea production in Nigeria. Even though the cowpea plant can grow well in nearly all parts of the country, cowpea pests are prevalent in the wetter southern part of the country, so that large-scale production of the crop occurs only in the drier northern part. As suggested by this cowpea example, the presence or absence of diseases and pests is often strongly influenced by climate. Finally, social and anthropological considerations may influence the choice of a particular region over another for crop production. Such criteria include access to cheap labour, ease of acquiring land, and the desire of the farmer to locate within his own ethnic group.

However, for most of the small-scale traditional farmers who constitute the bulk of farmers in the tropics, the question of choosing in which part of the country they should locate their farms never arises. For them, the farm is invariably located in their own ethnic region and in some cases, in their own native village.

Factors to consider in the final decision of the farm site are:

* availability
* soil
* slope
* irrigation facilities.

**Availability**
The site must, of course, be available for crop production. If it is not owned by the farmer or freely available to him, it must be available for lease or purchase at a reasonable price. There should also be room for possible expansion of the farm in later years.

**Soil**
The site must have soil that is good for crops. If the land is in bush and is to be cropped for the first time, the fertility should be high enough to sustain crop production for two or three years before the farmer moves away (in shifting cultivation) or needs to apply fertilizers (in continuous cropping). The soil reaction [pH] must be within an acceptable range. The soil structure and texture must also be good, and the salinity low.

**Slope**
The land should be flat or slope gently. Land with a steep slope will later create erosion problems.

**Irrigation Facilities**
Irrigation water should be available on the land without much difficulty. This is particularly important if continuous cropping is
envisaged. It may not be possible to utilize the irrigation facilities within the first few years of establishing the farm, but as the farm and its needs grow, there should be a ready source of irrigation water to enable year-round crop production to take place on the farm. The source of irrigation water could be a stream which could be dammed to impound water for irrigation. In the absence of streams, underground water should be readily available through boreholes.

CLEARING
Once the site for the farm has been selected and acquired, the farmer proceeds with clearing. This involves cutting down the vegetation that is growing on the land, and then removing the dead plant material from the cropping area.

In traditional practice, the plant material is cut down with cutlasses, axes and saws. Most of the underbrush and smaller plants are cut down with cutlasses, while the shrubs and trees are cut down with axes and saws. In the traditional setting, clearing is almost always selective. The kinds of trees which are left standing fall into three groups:

* any economic trees such as oil palms, locust bean and shea butter trees which happen to be on the plot
* slender upright shrubs which will serve as live stakes for various climbing crop plants such as yams, cucumbers and lima beans that will be planted on the farm
* very large trees such as silk cotton and baobab, which are spared because of the high cost and labour required to fell them.

A special case of selective clearing occurs in the case of shade-loving crops such as cocoa and coffee. Most of the trees and shrubs are left standing in order to provide shade for the young crop trees. As the crop trees get bigger, the number of shade trees is gradually reduced until eventually all of them have been removed.

Clearing may be of considerable and immediate economic benefit to the traditional farmer, particularly in forested regions. The area that is cleared is subjected to maximum economic exploitation during the clearing. Wild fruits, vegetables and spices are collected as they are encountered, to be taken home at the end of the day for domestic use. A significant number of wild animals such as rabbits, grass-cutters and deer are also killed and taken home during the clearing operation. This is in addition to other slow-moving animals such as snails and tortoises that are also collected. The stems of various twining plants are cut and saved for use as rope, while
slender erect stems encountered during clearing are cut and saved for later use as stakes. In short, the traditional farmer carries out a general harvesting of the forest during the clearing operation.

After the vegetation has been cut down, the traditional farmer resorts to burning in order to remove the plant debris. Usually the vegetation is allowed to dry for a few days or weeks before it is set on fire. For this reason, the cutting down of the vegetation and the burning are done during the dry season preceding the cropping season. The advantages and disadvantages of bush burning as a method of vegetation removal have already been discussed in Chapter 7.

The use of bulldozers and other kinds of heavy machinery for land clearing has become widespread in recent years. The bulldozers operate by uprooting the trees and shrubs and pushing all the plant material to some designated corners of the field. The advantages of this system are that the clearing is relatively cheap and that the problem of stumps is not so acute since most of the trees are removed with their roots. Moreover, land clearing with bulldozers obviates the necessity for burning, with its attendant disadvantages. The debris is removed from the cropping area mechanically rather than through burning.

The use of bulldozers for land clearing has two main disadvantages:

* bulldozers are relatively heavy and cause considerable soil compaction
* the operation of the bulldozer often deprives the soil of much of its organic matter. This occurs in two ways. The operation of the bulldozer tends to scrape away a lot of the surface organic matter as well as a significant quantity of the top soil. Secondly, by pulling plant roots out of the soil, the organic matter that would have been contributed by the decomposition of those roots is denied to the soil.

Bulldozers are also heavy consumers of fossil fuels and their continued use will remain economical only as long as such fuels are cheaply available. Moreover, the use of bulldozers is likely to be quite limited in swamplike areas and regions where there are no adequate infrastructures for their use and maintenance.

After the land has been cleared of plant debris mechanically or through burning, it is often necessary to go through it to remove tree stumps and woody roots. This procedure is called stumping. As has been previously mentioned, stumping is essential if mechanical tillage equipment is to be used on the field. If they are not removed,
stumps and tree roots may result in considerable damage and breakage of ploughs and other tillage equipment. Stumping is a fairly tedious operation and even though most of it is done shortly after clearing, some stumping will continue to be necessary from time to time during the first few years of continuous cropping. In shifting cultivation, where only limited tillage is to be done, stumping is much less important, although it could still be beneficial in such situations.

The dimension and complexity of land clearing depends on the native vegetation on the land. Clearing is most complex and tedious in the tropical forest regions where the land has to be cleared of forest before cropping can occur. In grassland regions clearing is much less tedious. The use of the machete is prevalent and there are very few trees to be cut down. Indeed, the few trees available are invariably spared to provide shade. Burning too, is a common practice for getting rid of plant debris in grassland regions. However, where the grass is particularly sparse, cropping could conveniently be done after clearing but without removing the plant debris. Such debris, if left, could serve as a mulch and contribute to soil organic matter. A similar practice of cropping without removing cut vegetation is sometimes possible in forest regions. Stumping too, is less imperative in grassland regions, since grass roots constitute little problem for most tillage equipment. Where land clearing machinery is employed in grassland areas, lighter and less powerful versions of the machines can be conveniently used, reducing soil compaction.

In shifting cultivation, land clearing has to take place nearly every year, and is one of the inefficient aspects of the system. In continuous cropping, the major land clearing needs to be undertaken only once. However, land clearing may need to be done after short-term fallow periods, but the clearing is of a less tedious nature, resembling land clearing in grassland areas. As land pressure and improved technology force more African farmers to change from shifting cultivation to continuous cropping, the importance of land clearing in African agriculture is expected to decrease.

**TILLAGE AND LAND PREPARATION**

Tillage in its broadest sense has been defined in recent years as changing a soil's condition or position with a tool, for man’s benefit. After the land has been cleared and the plant debris removed, it is often necessary to subject it to some form of tillage before the crop is planted. Various forms of tillage may also be carried out while the crop is growing on the field, or even during fallow periods.
Purpose of Tillage
In general, tillage is carried out for one or a combination of the following reasons:
* seed bed preparation
* control of weeds
* incorporation of organic matter into the soil
* soil and water conservation
* improvement of the soil's physical condition.

Seed bed preparation
Tillage loosens the soil and results in a seed bed suitable for seed germination and the development of the young seedlings. A good seed bed should be moist and should not contain large lumps of soil that may prevent close contact between the planted seed and soil particles. It should also be devoid of excessive quantities of undecomposed vegetation.

Control of weeds
Often weeds growing on a fallow plot can be controlled by being ploughed under. Ploughing prior to cropping may also serve to kill the weeds present. Tillage between rows of growing crop can be an important method of weed control.

Incorporation of organic matter into the soil
Organic matter and crop residues can be incorporated into the soil through tillage. Once in the soil, they are able to decay more rapidly so that their nutrients can be made available to the growing crop. The incorporation of plant residues in the soil through tillage also serves to improve soil structure.

Soil and water conservation
Tillage often serves the purpose of breaking up the surface layers of the soil so that water is able to infiltrate more readily into the soil. This has the dual benefit of increasing the amount of water available in the soil for the crop and of decreasing the amount of soil erosion caused by excessive run-off. For these reasons, land that is not to be cropped immediately may even be occasionally ploughed or tilled as a soil and water conservation measure.

Improvement of the soil's physical condition
The physical condition of the soil can often be improved by tillage. For example, where the surface layers of the soil have formed a hardpan, it may be beneficial to break up the hardpan through tillage.
Types of Tillage

Ploughing
This one of the most ancient and most universal forms of tillage. A shear, which is pulled along by some power device, slices its way under the soil as it goes along, thereby loosening the soil and turning it over. The soil is left in lumps of various sizes and may require other operations in order to make a suitable seed bed. Ploughs differ in the exact structure of the shear, and in the source of power for pulling the shear along. Animals such as horses or oxen may be used to provide the power for the plough (Fig. 24). Tractor-powered ploughs are also quite common now, even in parts of the tropics where animal-powered ploughs were once predominant. In some areas, neither animal-powered nor tractor-powered ploughs are in use. Instead, the farmer uses human power and the wide-bladed hoe to loosen the soil and turn it over. In such regions, generalized ploughing of the entire field is rarely undertaken and ploughing is commonly combined with some form of soil collection such as mounding or ridging.

Harrowing
Planting may be done on the field after ploughing, but if the lumps of soil left after ploughing are too large, they must be broken up before planting. The conventional way to break up soil lumps is
through harrowing. There are various kinds of animal-powered and tractor-powered harrows but they all function by breaking up the lumps of soil and leaving an even soil surface. Where harrows are not available, a second ploughing may serve some of the purposes of harrowing. At the lowest level of technology, rakes and even sticks can be used to break up the soil lumps and smooth the soil surface.

**Soil collection**

The soil on the field is very often collected in various forms before the crop is sown (Fig. 25), so that some areas of the field are raised above others. The three most common forms of soil collection in the tropics are mounding, ridging and bed-making. In each case, the soil
collection may be done without ploughing, after ploughing but without harrowing, or after ploughing and harrowing.

**Mounding** (Fig. 26) involves the collection of the soil into more or less conical heaps or mounds. The mounds usually vary in height from 30–100 cm, but are usually of approximately the same height on a particular farm. The distance from one mound to the next also varies, but it is this distance that determines how much cropping can occur in the lower-lying spaces between the mounds.

Mounding is the most common form of soil-collection tillage in tropical Africa and is often associated with intercropping. Indeed, it is a tillage practice that is particularly adapted to intercropping since it simultaneously permits two or more kinds of seed bed on the field; the top of the mounds is used for crops such as tubers which require a deep layer of loose soil, the low-lying furrows are used for crops with a high water requirement, such as rice, while the slopes of the mound are used for intermediate crops.

Mounding has the advantages of:

* providing a deep, loose seed bed which is particularly suitable for the development of roots and tubers
* providing a variety of seed bed types on the same field, which may be advantageous to intercropping
* elevating the seed bed and plant roots above the water table in fields with a high water table.
The main disadvantage of mounding is that it has not been mechanized and will probably be extremely difficult to mechanize. All mounding is now done with hand-held hoes, and the process is not only laborious but also tedious and back-breaking. Other disadvantages include the fact that mounds impede the free movement of men and machinery through the field. For these reasons, mounding is mostly confined to traditional agriculture (with intercropping) to which it is well suited.

**Ridging** involves the collection of soil into elongated heaps called ridges. The distance between the ridges is variable, but is usually about one metre. Growing crops on ridges is quite common in tropical Africa. In the traditional setting, hoes and human labour are used to make the ridges, but mechanical ridgers are also available and permit large areas to be ridged in a relatively short time.

Ridging has the same advantages that have already been given for mounding. In addition, ridging is an extremely useful measure for erosion control, particularly on sloping land. In such cases, ridging (as well as ploughing) is done along the contour so that the flow of water down the slope is impeded. The water then flows along the furrows between the ridges. In order to further discourage the rapid flow of water within the furrows, cross ridges (also called cross bunds or tie ridges) are made across the furrow at intervals to connect one ridge to the next. If the cross ridges are not made, there is always the danger that the water flow in the furrows between the ridges may become so rapid as to break the continuity of one or more ridges. When this happens, the torrent of water that is unleashed usually causes great devastation to the field. Thus ridging, when properly done, can decrease surface run-off, thereby reducing soil erosion and promoting water infiltration into the soil.

Since it has been completely mechanized, ridging finds a place in modern agriculture, where it is the most common form of soil-collection tillage. It is also found in traditional agriculture, but there it is less prevalent than mounding. In semi-arid areas, the crop may sometimes be placed in the furrow between the ridges rather than on the ridges themselves. This is because the water supply to the crop is better in the furrows than on the ridges.

**Bed-making** is a form of land preparation which is more often encountered in horticultural and nursery practices than in field crop production. A bed is like a ridge in that it is an elongated raised portion of the field. It is, however, usually much broader than a ridge, its top is flat, and its length is usually not more than 20 m. The top of the bed is therefore very much like the surface of a well-harrowed field, the main difference being that the bed has a deep layer of loose soil beneath it. Bed-making is most commonly done
with hand tools, but this is not too serious a handicap since the land areas involved are usually small.

**Intertillage**
Intertillage is commonly practiced with respect to crops that are planted in rows. It involves tilling the areas between the crop rows. Its objectives are usually to control the weeds between the crop rows, and to promote water percolation into the soil.

**Grading and Terracing**
These are two land preparation operations which aim at effecting changes in the gross topography of the field. Grading is most commonly done where it is desired to use furrow or some other form of surface irrigation. In such cases, the slope of the land must be such as to permit the desired rate of water flow through the field. The land is of course so graded that the point of water supply is the highest on the field, and the field slopes downwards from the water source. However, the exact degree to which the field is graded requires detailed mathematical calculations, and is governed by such factors as soil texture, the length of the furrow, the rate of water supply and the nature of the crop.

The grading of the crop field is also encountered where the farmer intends to impound water for the flooded culture of rice or taro in the tropics. If the land is sloping, it is graded to be relatively level. Elevated areas or dykes are constructed around the field so that the water does not flow away once impounded.

Terracing is one of the methods of managing extremely sloping land for crop production. It creates a series of relatively flat horizontal portions alternating with vertical portions, very similar to a flight of stairs. The flat portions are used for cropping. The construction of the terraces of course requires considerable earth movement and expenditure of money and labour. However, it provides erosion control and permits cropping on land that would otherwise have been useless for cropping.

A slightly different practice for cropping on sloping land is the use of contour bunds. These are narrow, elevated strips which are constructed along the contour. Cropping takes place between the bunds, while the bunds themselves are usually never cropped.

**Minimum Tillage**
There has been a realization in recent years that frequent tillage operations tend to impair the structure of many tropical soils. Moreover, it is suggested that frequent tillage unduly exposes the soil to the adverse effects of rainfall. Yet improved agriculture in many
tropical countries has tended to increase the frequency and intensity of tillage operations. These observations have led several scientists to develop the concept of minimum tillage. This entails that crop production should be carried out with as little tillage or soil disturbance as possible, as tillage is seen as a necessary evil which should only be sparingly indulged in. Some scientists even propose that crop production should be possible with no tillage at all (zero tillage). Proponents of the system point to the existence of several traditional communities whose farming systems have survived through the centuries on the basis of minimum tillage.

The advantage of minimum tillage are certainly real. Not only is the soil structure preserved, but the system is also more economical, since the labour and cost normally incurred in tillage operations can be saved. However, some of the advantages of tillage, such as weed control, will be difficult to replace under zero tillage. The suggested practice of using only herbicides to clear weeds after fallow and during cropping will be efficacious only in limited circumstances and may have long-term adverse implications for the environment. For the present, the best position seems to be that some amount of tillage should continue to be practised but only where and when it is absolutely necessary.

SOWING AND PLANTING THE CROP
Field crops are established either from true seeds or from some vegetative plant parts. Conventionally, the term sowing is used for seeds and planting is used when vegetative parts are involved. Sometimes the term planting is also used when there is no necessity to distinguish which type of material is placed in the soil. Examples of crops established by sowing seeds are groundnuts, maize, sorghum, millet, wheat, cowpeas and melons. Crops such as yams, sugarcane, sisal, ginger, cocoyams, sweet potatoes and cassava are normally established by planting vegetative parts.

Seeds and Seed Germination
A seed consists of a miniature plant (the embryo) enclosed in a wrapper (the testa). Sometimes a quantity of nutritive material (the endosperm) may also be enclosed in the wrapper. The embryo represents the new generation of the plant and it is the most essential part of the seed. It consists of a shoot axis (the plumule), a root axis (the radicle) and one or more seed leaves (the cotyledons). In seeds where the endosperm is absent, much of the food material of the seed is stored in the cotyledons.
The testa is the outer covering of the seed. It usually encloses the seed entirely except for a minute pore, the micropyle. The testa of various crop plant seeds can vary in consistency from being thin and papery, as in cowpea, to being thick and impervious, as in castor and cassava.

The process of germination involves the growth of the miniature plant (embryo) contained within the seed into a larger plant. The endosperm, where present, plays only a rather passive role, its main function being to supply food material to the growing embryo. The food material stored in the cotyledons is also utilized during germination.

The first event that occurs after a seed is sown in moist soil is that the seed imbibes water. This process causes the seed to swell and also results in the activation of various enzyme systems in the seed. For seeds to be able to imbibe water adequately they must be in good contact with moist soil. It is for this reason that the soil should be firmly pressed down over the seed after inserting it in the soil. Following imbibition, the food material present in the seed is hydrolysed; starch is hydrolysed to sugars, proteins to amino acids, and fats to fatty acids and glycerol. The products of hydrolysis are then translocated to the growing points, where they are used as building blocks for new cells, and as substrates for respiration to supply energy for various processes.

For seeds to germinate, certain environmental conditions must be fulfilled. First, water must be available so that when it is imbibed by the seed the metabolic processes within the seeds are enhanced. Secondly, oxygen should be present for aerobic respiration to occur so as to supply energy for the germination process. Thirdly, there should be an appropriate temperature.

The morphological changes occurring during germination vary greatly from seed to seed. In some, the cotyledons are carried above ground level due to the elongation of the region just below the cotyledons (hypocotyl). Seedlings whose germination occurs in this way are classified as epigeal. The seedlings of groundnut, melon, cowpea, onion, okro and castor are epigeal. Once the cotyledons have appeared above the soil they may quickly dry up and wither away, as in cowpea, or they may flatten out, become green and function for a long time essentially as foliage leaves, as in okro and melon. In contrast to epigeal seedlings are those in which the cotyledons remain at the level where the seed was planted and are not carried above ground. Such seedlings are classified as hypogeal. Rice, maize, guinea corn, rubber and broadbean seedlings are all hypogeal. It should be noted that examples of hypogeal seedlings include both dicots and monocots. The same is true of the epigeal group.
Seed dormancy
When a living seed fails to germinate even when provided with the normal conditions necessary for germination (i.e. water, oxygen and a suitable temperature) such a seed is said to be dormant.

Seed dormancy may be caused by the presence of an impermeable testa, or the presence of growth inhibitors in the seed. Alternatively, it may be caused by the need for a cold treatment or for exposure to certain photoperiods before the seed can germinate.

The phenomenon of dormancy is not peculiar to seeds alone. Tubers, such as those of yam, may also exhibit dormancy and be incapable of sprouting until some time after harvest.

From the farmers' practical standpoint, seed dormancy is important because dormant seeds will not readily germinate when sown and the farmer may have to incur additional cost in trying the break dormancy. Fortunately, the seeds of most tropical crop plants do not exhibit appreciable dormancy so that it is only in rare instances that steps need to be taken to break it.

Sprouting of the Vegetative Propagule
Where a crop is grown by planting a vegetative part (propagule), then the sprouting of the propagule, rather than seed germination, becomes the important consideration. The two main kinds of vegetative propagules used for tropical field crop production are stem cuttings and pieces of tubers or rhizomes. Occasionally tubils may be used, as in sisal and the aerial yam.

Stem cuttings are the normal commercial method for propagating cassava, sugarcane and sweet potatoes. Once planted in moist soil, the establishment of the stem cutting depends on the rapid production of roots and sprouts. The formation of roots by the stem cutting usually occurs at the older portions of the planted piece that are below soil level. This process is facilitated by auxin which diffuses down from the buds and younger parts of the cutting to the older parts where it promotes rooting. Rapid rooting is extremely important for the establishment of the stem cutting. This is because rooting must occur for the cutting to obtain adequate water and nutrients from the soil. If rooting does not occur rapidly enough, the cutting may dry out and fail to establish. This emphasizes the importance of the soil being moist at the time the cutting is planted. If the soil is dry, rooting fails to occur or is extremely slow, so that the cutting will fail to establish even if water is supplied later. In certain plants where rooting normally occurs slowly, its rapidity can be improved by dipping the base of the cutting in a preparation of synthetic auxins such as indolebutyric acid or napthoxyacetic acid.
The production of shoots (sprouting) by the cutting is not as immediately necessary as the production of roots after planting but is just as important in the long run. The initial growth of the sprouts occurs at the expense of the food reserves of the cutting. The sprouts arise as a result of the elongation of the axillary buds present on the stem cutting. The leaves produced during sprouting will of course become the main photosynthesizing organs of the plant, to sustain the plant when the food reserve initially present in the cutting have been used up.

The course of sprouting in tuber pieces depends on the crop type in question. In cocoyams and potatoes, buds are abundantly present on the tuber, so that sprouting essentially involves the breaking of the dormancy of those buds, and their elongation. The same is true of head pieces of yam. For non-head setts of yam, however, buds are absent from the propagule at planting, so that sprouting involves the formation of new buds and their subsequent elongation. In rhizomes, such as ginger, sprouting consists of the breaking of dormancy followed by the elongation of buds already present.

Seed Quality
There are several factors which contribute to quality in agricultural seeds. Some of these factors are more important for seeds which are intended for sowing, while others are equally important whether the seed is for sowing or for consumption.

Maturity
Immature seeds tend to store poorly, and in many instances may fail to germinate. This factor is certainly much more important for seeds that will be sown than for seeds meant for consumption. Sometimes the conditions prevailing during maturation may exert a profound influence on the later performance of the seed. In such cases, even seeds that have been allowed to develop to maturity may germinate poorly. Thus both the stage of maturity when harvested and the conditions prevailing during maturity are important factors in seed quality.

Wholesomeness
Injury, cracking or breakage of the seed will result in reduced germination. The extent to which a seed’s ability to germinate is impaired depends on the part of the seed that received the injury. Relatively large amounts of injury occurring in the endosperm or at the edges of the cotyledons may impair germination only slightly, while minute injury to the plumule-radicle axis may cause failure of
germination. Mechanical injury to seeds may also make them susceptible to diseases and pests and therefore reduce their storability. The market value of broken but otherwise good seeds is lower than that of whole seeds. Thus, wholesomeness of seeds is important, whether or not they are to be sown. Unfortunately much of the mechanical injury is inflicted on the seeds during seed cleaning and processing. Great care should therefore be taken when cleaning seeds, and the appropriate equipment should be used.

Diseases and pests
The presence of diseases and pests reduces the quality of seeds both for consumption and for sowing. The diseases and pests are usually present at the time the seed is stored and if appropriate measures are not taken, the extent of the infestation will increase during storage. Diseases impart an unpleasant odour and taste to the seed, while pests may consume the seed and degrade it with excrement. Diseased seeds germinate poorly and pests such as the cowpea weevil may damage the seeds and also cause poor germination. Seeds that are to be stored are commonly protected from diseases and pests by treating them with appropriate pesticides (usually fungicides and/or insecticides). This procedure is referred to as seed dressing.

Foreign matter
The presence of foreign matter in the seed lot reduces its quality. Inert foreign matter such as stones and dried plant material are objectionable, particularly in seeds destined for consumption. Even more objectionable are weed seeds which may pose grave problems when the seeds are sown. Moreover, the weed seeds may promote spoilage of the seed lot during storage.

Viability and germination tests
The overall worth of a batch of seeds for planting can be assessed by means of viability and germination tests. Viability tests are intended to distinguish living seeds from dead seeds. In their more refined forms, they can also distinguish between living and dead portions of the same seed and serve as a basis for predicting germination. The most common viability test is that which utilizes 2,3,5-triphenyltetrazolium chloride (TTC). The seeds are soaked in water for a few hours and then cut into two. The seed halves are then soaked in a 1% solution of TTC in the dark for one or two hours. At the end of this period, the embryos of living seeds will stain reddish, while
dead embryos or dead parts of the embryo will remain un-
stained. The test depends on the ability of enzymes in the living
tissues to reduce the colourless TTC to produce the reddish-
coloured formazan. Other viability tests are those which utilize
indigo carmine stain or X-rays, but these are much less commonly
used.

Since dormant seeds are also living, they give a positive viability
result, just as non-dormant living seeds. The viability test, therefore,
gives no indication of the immediate ability of the seed to germinate
but only indicates whether the seed is alive. Knowing that the seed is
alive is not of sufficient practical use to the farmer. In most
instances, he is more interested in whether or not the seeds will
immediately germinate when sown, and what percentage germina-
tion can be expected. Germination tests have therefore been devised
to distinguish between seeds which can germinate immediately and
those which cannot because they are either dormant or dead. In the
germination test, batches of the seeds are germinated under optimal
conditions and the percentage germination is determined. The
seeds may be scattered on moist paper or a cloth towel. The towel is
rolled up and placed in the dark at around 30°C. After about 9 days,
the percentage germination is determined. Usually the test is run on
several samples taken from each seed lot in order to minimize error.
Once the germination percentage of the seed lot is known, it is
possible to predict its field emergence and adjust the field seeding
rate accordingly.

Seed Certification
In most developed countries and in some countries of tropical
Africa, there are agencies or seed associations which are charged
with the responsibility of overseeing seed quality. It is their duty to
certify seed that is intended for sowing, using most of the quality
criteria discussed above. Their activities include the monitoring of
the locations where seed is produced, grading the seeds, carrying
out viability and germination tests, certifying the seeds, and in some
cases distributing certified seed. The speciality production of seeds
for sowing has not become widespread in tropical Africa. It is,
however, gaining ground and the importance of seed certification
will continue to increase.

The quality of commercial seeds that are not intended for sowing
is usually overseen by other agencies such as marketing boards.
These boards determine the criteria for grading the seeds of each
crop type, as well as determining the minimum requirements for
each grade of seed.
Seed Placement in the Field
There are four general aspects to seed placement in the field:

* the number of seeds sown at each spot (stand)
* the spacing between stands
* the depth to which the seeds are placed
* the position of the seed with respect to the previous tillage operations, i.e. whether the seed is sown on the ridge or mound, in the furrow, on the slopes of the ridge, or on the flat.

Number of seeds per stand
The number of seeds sown per stand depends on the expected percentage germination of the seed, and the number of plants desired per stand. The expected percentage germination is ascertained by prior germination tests, and if it is low, the number of seeds sown per stand is commensurately increased. If, for example, the germination percentage is 50% and we desire two plants per stand, then four seeds should be sown on each spot, so that on average we will have two plants per stand. Sometimes the number of seeds sown on each stand is kept deliberately high, so that the number of plants appearing on each stand is higher than the desired number (usually one or two). When the seedlings are well established, the extra plants are removed, leaving just the desired number per stand. This procedure of removing excess emerged seedlings is referred to as thinning. The main advantages of deliberate over-seeding and subsequent thinning are that it provides the opportunity to select out weak seedlings while retaining the vigorous ones and that, after thinning, nearly every stand has the correct number of seedlings. In contrast, when we attempt to achieve the correct number of plants per stand directly by not exceeding the appropriate seeding rate, we may find that some stands have too few plants and other stands too many. However, the fact that thinning is laborious and expensive tends to detract from its advantages.

Spacing between stands
The decision as to the appropriate number of plants per stand is based on experimental evidence and depends on the kind of crop. Crops where each plant is relatively large, such as cassava and tree crops, are invariably grown at one plant per stand. Medium-sized crops such as maize and guinea corn can tolerate two plants per stand, while for small-sized crops such as rice two or more plants per stand is the rule.

The spacing between stands is largely determined by the extent of the root and shoot systems of the crop plant in question. The spacing determines the size of the land area available to each plant or stand,
and the larger the plant the greater the area required for it to perform well.

Once the area required by each plant is determined, the question of the shape of this area then arises. A plant requiring 1,600 cm² could have this in the form of a square of 40 × 40 cm, a rectangle measuring 80 × 20 cm, 160 × 10 cm etc., or even a circle of appropriate radius. The shape of the area is determined by the geometric pattern in which the crop is planted on the field. The spacing between the crop rows is usually adjusted to what mechanical planters can cope with, and the optimum spacing within the row is determined experimentally or from experience. In the unmechanized situation where the spacing between rows can be freely adjusted, it is possible to obtain reasonable yields from various combinations of row widths and within-row spacings, as long as the rectangle does not become too narrow.

Sometimes sowing is done by scattering the seeds at random on the field or plot. This method of sowing is referred to as broadcasting. In this case there is no fixed geometric pattern and both the shape and size of the area available vary from plant to plant. Broadcasting is most commonly used to sow small seeds such as rice on the field or vegetable seeds in the nursery. A slightly different method of seed sowing is drilling in which the seeds are sown in a continuous band in rows. As such, the space between the rows is fixed and can be determined, but the spacing within the row in indeterminate. Like broadcasting, drilling is most commonly used for small seeded crops.

The spacing between stands determines the number of stands per hectare. The number of stands per hectare, and the number of plants per stand together determine the number of plants per hectare, or the plant density. The two components that determine plant density can sometimes compensate for each other. For example, a slight decrease in the number of stands per hectare may not necessarily reduce yields if the number of plants per stand is commensurately increased.

**Depth of sowing**

The depth at which the seed is placed in the soil is influenced by:

* seed size
* type of germination
* moisture status of the soil
* soil type.

*Seed size*: the larger the seed, the greater the depth from which it can emerge and the deeper it can be safely sown. This is because
large seeds have ample quantities of stored food material for the germination process. As such, they produce vigorous seedlings which have enough stored food for the long time it may take to emerge from great depths. Small seeds, on the other hand, tend to deplete their stored food in a short time.

Type of germination: the type of germination exhibited by the seeds of a species influences their ability to emerge from great depths. Seeds with epigeal germination have to push their cotyledons to the surface and therefore have limited ability to emerge from great depths. Among the cereals, those such as maize and rice, in which emergence is accomplished by the growth of both the coleoptile and the internode below the coleoptile, can emerge from greater depths than those such as barley, in which the sub-coleoptile internode fails to elongate.

Moisture status of the soil: as wet soil dries out after rain or irrigation, the surface layers are the first to dry while the deeper layers retain their moisture much longer. Under dry condition, therefore, seeds should be sown deeper in order to place them in contact with moist soil.

Soil type: all other factors being equal, seeds can emerge from greater depths in sandy soil than in clay soil. Sowing depth can therefore be adjusted according to soil texture.

**Position of seed with respect to land preparation**
The position at which the seed is sown with respect to land preparation depends on the nature of the crop and climatic factors. Under waterlogged conditions, the seed is normally planted on top of the mound or ridge so that it is removed from the high water table. At the other extreme is the situation in dryland areas where planting the crop in the furrow may ensure greater moisture availability.

**Placement of Vegetative Propagules**
The foregoing principles of seed placement in the field are also generally applicable to the planting of vegetative propagules. Because of the large quantity of stored food that they usually contain, such propagules are capable of emerging from much greater depths than seeds. As a rule, however, they should not be planted more than 3–10 cm deep in the soil. An additional consideration with respect to vegetative propagules is their orientation. Stem cuttings fail to sprout or perform poorly if planted in an inverted position.
Time of Sowing or Planting
Several factors influence the time of sowing or planting. They are:

* rainfall
* temperature
* day length
* occurrence of diseases and pests
* marketing
* cropping system
* availability of labour and equipment.

Rainfall
Rainfall or the availability of moisture is one of the principal factors which determine when a crop should be planted. On a seasonal basis, the crop should be planted at a time when there will be enough subsequent rainfall to see it to maturity or full establishment. For this reason, the planting of long season annual crops such as yams must occur at the beginning of the rainy season so that the crop has the entire rainy season available to it for development. For perennial crops such as cassava, cocoa and rubber, planting in the field early in the rainy season is also advisable, so that the crop can become established before the dry season sets in. For short-season annuals such as cowpeas, sweet potatoes and maize, planting may be delayed till later in the rainy season, as long as the crop can complete its growth and development before the onset of the dry season. Sometimes the intention is to let the maturity period (or another stage of the crop) correspond with a rainless period. For example, the sowing of cowpeas or millet is often timed so that the crop matures during a dry period.

On the narrower scale of determining on which exact day planting should occur, rainfall also plays a crucial role. Planting should normally be done in moist soil to allow for rapid seed germination or sprouting of the vegetative propagule. For this reason, planting is normally done within a few days after rain. On the other hand, excessive rainfall at the proposed time of planting may cause the soil to be waterlogged and force a postponement of the operation. This is particularly true if mechanical planters are to be used. Where rainfall occurs throughout the year, or where irrigation is normally available, the influence of rainfall on the time of planting is considerably diminished.

Temperature
Temperature is another climatic factor that influences the time of planting. In the temperate regions, this aspect is crucial, but in the tropics it assumes appreciable importance only at high altitudes,
where planting should be done when the soil is warm enough to permit rapid germination. In other parts of the tropics, especially in the drier regions, excessively high temperatures may adversely affect seedling emergence. In such situations, however, rainfall rather than the high temperature is the main factor influencing the time of planting.

Day length
Day length or the photoperiod is a third climatic factor that may influence the time of planting. The crop should normally be planted at a time that will permit the appropriate photoperiod to exist at the flowering or tubering stage. For example, some okro varieties which require short days for flowering, will remain vegetative for most of the rainy season while long day conditions persist. The planting of such varieties could conveniently be delayed so that short-day conditions for flowering exist shortly after the plants are fully established.

Occurrence of diseases and pests
The occurrence of diseases and pests may influence the time of planting. The strategy is usually to adjust the time of planting so that the crop is on the field during the time when its diseases and pests are least prevalent. Cowpea production in southern Nigeria, for example, has been strongly influenced by this factor. Cowpeas sown in the early part of the rainy season are bedevilled by numerous diseases and pests but if sowing is delayed until the latter half of the rainy season, the incidence of diseases and pests is less severe and a decent yield can be obtained. Since the intensity of disease and pest occurrence is often influenced by climate, this factor can sometimes be an indirect effect of climate.

Marketing
Market considerations may also influence the time of planting. This is particularly true of vegetables and other crops which cannot be stored for long. Planting is timed so that harvesting occurs when the crop can command a good market price. Since the first batch of crops such as tomatoes, fresh maize and leafy vegetables usually attracts an extremely high price, farmers usually place a high premium on earliness in planting these crops and may even produce them with irrigation during the dry season.

Cropping system
The place of a crop in a rotation or in an intercropping system may determine at what time of the cropping cycle it is planted. For
example, many intercroppers in West Africa usually plant their cassava in the latter part of the rainy season after some of the earlier intercrops such as maize, okro and melon have been harvested. The cassava could have been planted earlier, but it is made to wait until the harvesting of the earlier intercrops creates enough space between the yam plants.

**Availability of labour and equipment**

The availability of labour, equipment and processing facilities are other factors that may influence the time of planting.

If the foregoing factors permit a crop to be planted at various times of the year, then it should be possible to grow more than one crop each year if it is a short-season crop. This is known as **multiple cropping** and is practised in various parts of tropical Africa for such crops as rice, maize and tomatoes. Production techniques may differ slightly between the same crop grown in various seasons, and the expected yields also vary. For example, late maize in southern Nigeria requires less fertilizer and usually yields lower than early maize.

**Emergence and Seedling Vigour**

Emergence is the appearance of the seedling above the ground. Even though germination occurs only a few days after planting, it occurs quietly in the soil, unnoticed by the farmer. The emergence of the seedling above the ground is the first visible assurance to the farmer that germination has occurred and that the seedling is now on its way towards establishing itself. The significance of emergence, therefore, is that it is the first opportunity for the farmer to see how effective the seeding operation has been. For the seedling too, emergence marks its earliest opportunity to make contact with sunlight and to begin photosynthesis which will eventually free it from its dependence on the food reserves carried over from the seed.

From the farmer’s standpoint there are three important aspects of emergence:

* time from planting to emergence
* final percentage emergence
* uniformity of emergence.

The time to emergence should ideally be as short as possible, so that the seedling can attain independent existence before the seed reserves have been depleted. The time to emergence is influenced by temperature, the time to germination, the sowing depth, the nature of the soil and the vigour of the seedling. Time to emergence
is short if germination is rapid, the temperature is moderate (25–30°C), sowing depth is shallow, the seedling is vigorous and the soil is light, loose and free of surface crust.

The final percentage emergence is the percentage of seeds sown that eventually emerge. It is this percentage that determines the nature of the stand obtained. If the percentage is low, the stand is poor and irregular and the farmer might contemplate replanting. The commonest cause of poor emergence is poor germination but there are several instances of germinated seedlings failing to emerge. This may be due to very low vigour of the seedlings, sowing at too great a depth, the attack of diseases and pests or extremes of temperature which severely retard the growth of the seedlings.

The uniformity of emergence indicates whether all the seedlings that emerged did so simultaneously (i.e. on the same day) or whether there was a long period between the early emersers and the late emersers. Uniform emergence is important because it ensures that all the plants on the field are at approximately the same stage of development. As a result, operations such as fertilizing or harvesting, which depend on timing, can be accurately programmed. The uniformity of emergence is influenced by the uniformity of germination; non-uniform germination will usually result in non-uniform emergence. The use of dormant seeds can also result in non-uniform germination and emergence.

The occurrence of emergence enables the farmer to determine the three above aspects of emergence. In addition to these, however, a further crucial factor in emergence is the vigour of the seedlings. Although seedling vigour could be determined experimentally as soon as germination starts, on the field the farmer is only able to assess the vigour of his seedlings after they have emerged.

Neither germination nor emergence guarantee that the seedlings will develop normally and yield well. The vigour assessment is therefore an indication of the health of the seedlings and of the likelihood that they will yield well. Factors which tend to lower seedling vigour are small seed size, the presence of pathogens in the seed or in the soil, protracted storage of the seed, and an adverse environment during germination.
WEEDS AND WEED CONTROL

WEEDS
A weed is a plant growing where man does not want it to be. Almost any kind of plant can therefore be a weed, as long as it exists in a location or situation where it is considered undesirable. It also follows that a kind of plant may be a weed in one situation and not a weed in another situation. For example, volunteer sweet potato plants in a crop of maize can rightly be called weeds even though sweet potato is normally a crop plant.

There are, however, several plant species which are encountered only as weeds in crop production. Such species usually possess several characteristics which enable them to compete effectively with crop plants and therefore to survive over the generations in association with crop production. Such characteristics include the following:

* the ability to flower and produce seeds in a short period of time. This characteristic means that the weed species is able to complete its life cycle even if the favourable season for growth is relatively short. In some cases is also enables the weed species to produce several generations each year.
* the ability to produce large numbers of seeds
* the presence of efficient mechanisms for seed dispersal. The main agents of seed dispersal for weeds are wind, animals (including man) and water. Most weed seeds are adapted to be dispersed by one or more of these agents. The possession of feathery structures as in milkweed, or of wings, tends to facilitate wind dispersal. Adaptations for water dispersal include a low density of the seed, as well as the possession of membranous structures or cork on the testa. These adaptations enable the seeds to float on water and to be carried for long distances. To aid animal dispersal, many weed seeds or fruits possess hooks or barbs with which they can stick to the skin of animals and the
clothing of humans. For example, the seeds of Bermuda grass are usually spread in this way.

* the presence of allelochemicals that inhibit the growth of crops or other weeds, such as in Siam weed (*Chromolaena odorata*).

* the possession of specialized seed dormancy mechanisms. Such mechanisms include impervious seed coats, the presence of growth inhibitors and requirements for exposure to certain temperature or light treatments. The net effect of these dormancy mechanisms is that seed germination occurs only under conditions that will enable the plant to complete its life cycle. As a corollary to this, weed seeds are able to survive in the dormant state in the soil for several years, only to germinate and grow when they are brought to the surface or when environmental conditions are appropriate.

* the ability to survive in a wide range of environments. This versatility in environmental adaptation of the weed plant increases the number of cropping situations in which the weed can grow.

* the presence of perennating organs. While annual weeds ensure their survival through copious seed production, perennial weeds are additionally endowed with vegetative perennating organs such as rhizomes, corms, tubers and bulbs. These organs not only enable the weed to survive from season to season, but they also enable the weed plant to re-grow each time it is cut off at soil level by the farmer.

* the ability to propagate vegetatively. Many weed species are able to propagate themselves from pieces of stems and roots. Thus when the plant is cut into pieces during weeding or tillage operations, each piece is able to give rise to a new plant. For example, the ability of the morning glory plant to propagate itself in this way makes it a difficult weed to control.

* the ability to resist chemicals. Weeds that are able to develop such resistance are additionally favoured by the fact that the chemical usually eliminates other weeds that would normally have competed with the resistant weed.

Table 8 lists some of the major weeds in tropical Africa.

The Harmful Effect of Weeds

One of the most easily observable effects of weeds is that they decrease crop yields. This occurs mainly because the weeds compete with the crop plants for water, mineral nutrients and light. The competition for water and mineral nutrients is most severe and crops yields are most depressed when either of these factors is in
### Table 8: Some common weeds in tropical Africa

<table>
<thead>
<tr>
<th>Common name</th>
<th>Botanical name</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bahama grass</td>
<td><em>Cynodon dactylon</em></td>
<td>Perennial; propagates vegetatively and by seed</td>
</tr>
<tr>
<td>Lalang</td>
<td><em>Imperata cylindrica</em></td>
<td>Perennial; propagates vegetatively and by seed</td>
</tr>
<tr>
<td>Bamboo grass</td>
<td><em>Paspalum conjugatum</em></td>
<td>Perennial; propagates vegetatively and by seed</td>
</tr>
<tr>
<td>Elephant grass</td>
<td><em>Pennisetum purpureum</em></td>
<td>Perennial; propagates vegetatively and by seed</td>
</tr>
<tr>
<td>Guinea grass</td>
<td><em>Panicum maximum</em></td>
<td>Perennial; propagates vegetatively and by seed</td>
</tr>
<tr>
<td>Goose grass</td>
<td><em>Eleusine indica</em></td>
<td>Annual</td>
</tr>
<tr>
<td>Crab grass</td>
<td><em>Digitaria sanguinalis</em></td>
<td>Annual</td>
</tr>
<tr>
<td>Foxtail</td>
<td><em>Setaria spp.</em></td>
<td>Annual</td>
</tr>
<tr>
<td>Milkweed</td>
<td><em>Euphorbia spp.</em></td>
<td>Broad-leaved weed</td>
</tr>
<tr>
<td>Portulaca</td>
<td><em>Portulaca oleracea</em></td>
<td>Very effective in vegetative propagation</td>
</tr>
<tr>
<td>Sedges</td>
<td><em>Cyperus spp.</em></td>
<td>Propagates by seed, and vegetatively by producing nut-like rhizomes</td>
</tr>
<tr>
<td>Eupatorium</td>
<td><em>Eupatorium odoratum</em></td>
<td>Broad-leaved weed</td>
</tr>
<tr>
<td>Goatweed</td>
<td><em>Ageratum conyzoides</em></td>
<td>Broad-leaved weed</td>
</tr>
<tr>
<td>Pigweed</td>
<td><em>Amaranthus spinosus</em></td>
<td>Broad-leaved weed</td>
</tr>
<tr>
<td>Tridax</td>
<td><em>Tridax proculbens</em></td>
<td>Seeds numerous and adapted for wind and animal dispersal</td>
</tr>
</tbody>
</table>

---

**Fig. 27 Eupatorium odoratum**, a noxious weed
short supply. The competition for light, on the other hand, depends on the canopy structure of the crop and the weed and upon their relative times of establishment. A tall-growing weed in a prostrate crop, such as goatweed in melon, is likely to compete more severely for light than a prostrate weed in a tall crop, such as Portulaca in maize.

The ability of the crop plant to compete against weeds varies with the stage of development of the crop plant. Usually, the competitive ability of the crop is low during the seedling and early vegetative stages, but tends to improve as the season progresses. For most crop plants, certain stages of development are particularly sensitive to weed competition. Once such stages have been identified, the farmer ensures maximum weed control at those times, while permitting less stringent weed control during the other less critical stages. In yams, for example, the crop is particularly sensitive to weed competition during the first two to three months after emergence, and failure to control weeds during that period results in lower yields than failure to control weeds during the latter part of the season (Kasasian and Seeaye, 1969).

The density of the crop plant can also influence its competitive ability against weeds. A high crop density, by providing a dense canopy, may control weed seedlings by depriving them of light. It is for this reason, for example, that closely spaced cassava experiences little or no weed problems after the first three months, whereas widely spaced cassava plantings (as practised by many subsistence farmers in Africa) suffer from weed problems throughout their field life.

In some cases, the weeds compete with the crop plants not just passively by drawing from the same pool of resources, but actively by producing substances that inhibit the growth and development of the crop plant. Such substances could be secreted into the soil environment while the weed is alive or might be released to the soil when the weed roots decay. The decaying roots of quackgrass (*Agropyron repens*), for example, release substances which inhibit the germination and growth of various crop seedlings. Another form of aggressive competition occurs when the weed plants are actually parasitic on the crop plant. Good examples of parasitic weeds include the dodder plant (*Cuscuta* spp.) and witchweed (*Striga asiatica*). Both of these attack a wide variety of crop plants including maize, sugarcane and guinea corn.

Competition is only one of the ways in which weeds reduce crop yields. Weeds can also reduce yields indirectly by serving as reservoirs for various diseases and pests of crop plants. This factor is particularly critical in the carry-over of disease organisms and
pests from one season to the next. The destruction of crop residues at the end of each season is usually intended to prevent the existence of the disease organisms in the crop stubble during the off season. However, certain weeds can completely frustrate the farmer’s efforts in this respect by harbouring disease organisms and pests during the off season and serving as a source of new infection or infestation during the subsequent season. In other instances, the weed may even assume the more prominent role of being an alternate host for a disease organism, so that the organism cannot complete its life cycle unless that weed species is present. The classic example of this is the wheat rust disease, in which the barberry weed plant is a necessary alternate host.

Weeds often reduce the quality of the harvested crop. In the case of grains, weed seeds often contaminate the harvested grain and reduce its quality. Such seeds often cause the harvested grain to deteriorate rapidly in storage. In other instances, it is the leaf and shoot debris that contaminate the harvested product. For example, weed debris sticking to harvested cotton lint tends to reduce its quality.

Weeds in pastures can be a nuisance or even a danger to livestock. Such weeds may be spiny or poisonous and therefore cause considerable discomfort or even the death of the livestock which ingest them. In other instances, weeds such as the wild onion can impart an undesirable flavour to the milk of dairy animals. Spiny weeds such as the wild yam and those which produce certain kinds of pollen may also pose considerable health hazards to humans working on the farm.

Other farming situations in which weeds cause problems include the clogging of canals and irrigation channels as well as damage to farm machinery through clogging by weeds.

In terms of economics, weeds add considerably to the cost of crop production. It is not just that they consume the water and nutrients which are provided for the crop at some cost; the farmer also has to spend an appreciable percentage of his annual budget on various weed control measures.

WEED CONTROL
From the above discussion, it is clear that weeds must be controlled for profitable crop production to take place. There are several ways in which weeds can be controlled and they can be classified generally as physical, biological and chemical methods of weed control.
Physical Methods of Weed Control
The common physical methods of weed control are:

* hand pulling
* weeding with hand-held implements
* machine tillage
* mowing
* fire
* mulching
* flooding.

Hand pulling
This is one of the simplest and most ancient methods of weed control. It was the method practised by early man, and is still practised today in certain situations such as in the home garden. It is particularly useful for removing weeds that are very close to the crop stand (e.g. within the row) and where a minimum amount of soil disturbance is desired. It is also used where the weed species to be removed occurs in relatively isolated stands. For each weed that has been pulled by hand, destruction is usually nearly complete, since both the shoot and the underground organs may be removed by pulling. Care should be taken, however, that the pulled plant is not discarded in such a position that it has a chance to re-establish itself.

Weeding with hand-held implements
Hoeing with a hand-held hoe is also a widespread method of weed control. For millions of traditional farmers in the tropics, this is the main method of weed control. Both short- and long-handled hoes are used for this purpose, but the latter is preferable as one does not have to stoop while weeding. When hoeing, it is important to ensure that most of the weeds are cut below ground level so as to reduce the chance of weed regeneration. Quite often the farmer takes the opportunity while weeding with the hoe to mend any mounds and ridges that may have been reduced by erosion, as well as to place some soil around exposed crop roots.

Like hard-pulling, hoeing is most widespread where relatively small areas are cropped. It has the disadvantage of relying on human labour and in the case of the short-handled hoes, requires excessive stooping.

In many tropical communities, other hand-held implements are used for weeding instead of the hoe. The most common are the machete and the cutlass which can be modified in various ways to adapt them for weeding. These implements also require much
stooping and are suitable only for small areas. When clean weeding to ground level is not desired, such as when brushing between tree crops, the hoe is practically useless and the cutlass and machete are the implements of choice.

**Machine tillage**

One of the more technologically advanced methods of weed control is the use of the plough, the harrow or the cultivator. The plough and harrow are most often used to control weeds before the crop is planted (or in fallow plots) and between rows of the growing crop.

During ploughing, weed seeds that have remained buried in the soil are brought to the surface. They then begin to germinate and if shallow tillage is done shortly afterwards the weed seedlings are destroyed. This is a particularly good method for controlling annual weeds. For perennials, repeated tillage at relatively short intervals may be necessary. Each tillage operation destroys the top growth, and forces the weed plant to produce new growth at the expense of underground reserves. Eventually these reserves are exhausted and the plant dies.

Well-timed tillage operations can effectively counteract the profuse seed-producing capability of many weed species. Tillage should aim at destroying the weed plants before they reach the stage of setting seed. For this reason, even fallow or uncropped fields should be subjected to occasional tillage as a method of controlling weeds. The point here is that if the weeds are permitted to produce seeds on uncropped land, such seeds can easily be dispersed to the cropped fields. Those that are not dispersed may remain viable for several years and pose a problem when that particular field is eventually to be cropped.

**Mowing**

This is a weed control measure often practised between rows of tree crops, in pastures and along roadsides. One of its main purposes is to prevent the weeds from producing seeds and for this reason, it has to be done fairly frequently.

**Fire**

Fire is used as a weed control device in practically all parts of the world. In the developing countries of the tropics, it is used mostly to remove plant growth and plant material prior to cropping. Its use in land clearing in the tropics has already been discussed. In this context, it serves not only to remove the existing weed plants on the plot, but also destroys the weed seeds lying close to the surface.
Fire emitted from flame throwers is sometimes used to control small patches of weeds occurring along roads and railroad tracks. A more selective use of fire occurs where directed burners are used to control weeds in growing crops of onion, cotton, guinea corn or castor bean. This method of controlling weeds is called flaming.

**Mulching**

A mulch is a layer of non-living material placed over the surface of the soil. In addition to the other purposes which it serves (to be described below) mulch serves physically to smother the weeds and to cut them off from direct sunlight. In order to achieve a smothering effect, the mulch has to be relatively resistant to plant penetration. Where grass or other crop residue is used as mulch, it has to be in a relatively thick layer. Mulches consisting of a continuous layer of paper or opaque plastic are usually very effective for weed control.

In addition to controlling weeds, mulching also serves to:

* reduce evaporation from the soil surface
* prevent excessive heating of the soil during the day
* decrease soil-wash by breaking the impact of raindrops
* provide organic matter to the soil as the mulch decays.

**Flooding**

This is also an effective method of weed control, although its use is mostly limited to rice and taro which can be grown in flooded culture. Flooding kills the weeds by depriving them of oxygen. Since many weeds can survive flooding if they are not completely submerged, it is important to maintain the water level high enough so that no parts of the weeds are exposed.

**Biological Methods of Weed Control**

There are several ways in which biological factors can be manipulated to achieve weed control. The most dramatic instances are those in which natural enemies of the weed species have been identified and are either introduced or encouraged. With this approach, the prickly pear cactus has been controlled in Australia by the Argentine moth borer (Cactoblastis) and the Klamath weed has been controlled in the USA by the Klamath weed beetle. This approach is, however, most efficacious where a single troublesome weed species is predominant.

The adjusting of the planting density of the crop to achieve maximum crop competition with the weeds can rightly be regarded as a biological method of controlling weeds. A dense stand of the crop may be effective in reducing weed competition to a minimum. In some cases where the main crop competes poorly with weeds, an
aggressive intercrop planted at high density may be used to suppress weeds. This is the situation when a dense stand of edible-seed melon is used to minimize weed growth between stands of yam.

Crop rotation is another biological method of weed control. For many particular crop species, there are certain kinds of weeds which are able to compete well. Such weeds therefore tend to be associated with that particular crop. As a result, if a crop is grown in one location for several years, the associated weed species are favoured and become increasingly difficult to control as time goes on. Changing the crop species at regular intervals, as is done in crop rotation, regularly alters the competition dynamics so that no particular group of weeds is given the opportunity to entrench itself.

Chemical Methods of Weed Control
The use of chemicals to control weeds is essentially a phenomenon of the twentieth century. Even though various substances have been recommended for weed control for centuries, it is only in the twentieth century that scientists discovered substances which are toxic to weeds in small quantities and are relatively inexpensive. Today there are hundreds of chemicals which are used in various situations for the control of weeds. Such chemicals are called herbicides.

There are three criteria which can be used to classify herbicides:

* the time when they are normally applied
* whether or not they are selective
* whether they normally act through the shoot or the root.

Time of herbicide application
There are generally three distinct times when a herbicide may be applied. A pre-planting application is one that is done before the crop is planted. In this case, the herbicide may be one, such as paraquat, which is sprayed on the foliage of existing weeds to kill them, or it may be the type, such as trifluralin, that is incorporated into the soil during tillage operations. A pre-emergence herbicide application is one that is done after planting but before the crop has emerged. The weeds may or may not have emerged by the time of the pre-emergence application. If the weeds have not emerged, then a herbicide such as diuron or ametryne that acts on unemerged seedlings can be used. If the weeds have already emerged, a herbicide that can kill the established weeds could be used as well. A post-emergence herbicide application is done after the crop has emerged. Again weeds may or may not have emerged at the time of the herbicide application. A post-emergence herbicide application must find a way to avoid herbicide damage to the emerged crop. One solution to this is to use selective herbicides which will kill the
weeds and spare the crop. If non-selective herbicides are used the herbicide spray must be directed so as to avoid contact with the crop.

*Herbicide selectivity*

The property of selectivity in a herbicide implies that it is more damaging to certain groups of plants than to others. The ideal situation is one in which the predominant weed species are killed by the herbicide, while the crop species suffers little or no damage. The selectivity of a herbicide may be based on the relative amounts of the herbicide that are intercepted, retained, absorbed and translocated by the weeds and the crop. The formulation in which the herbicide is applied may have some influence on its degree of selectivity. Selectivity may also be based on a natural ability of the crop to tolerate a particular herbicide better than the weeds.

*Site of herbicide action*

Contact herbicides are those which kill the tissues at, or very close to, the point where they touch the plant. One should therefore ensure that the weeds are thoroughly covered by the contact herbicide spray. Such sprays are usually effective in eliminating annual weeds, but perennials and plants with underground reserves may be able to regrow later.

Contact herbicides may be selective or non-selective. Selectivity may be based on time of application, plant morphology, cuticle thickness, and directed spraying. Non-selective contact herbicides such as paraquat are particularly useful for total weed control along roads, railroad tracks and irrigation ditches.

Systemic herbicides are those which are absorbed into the plant and translocated to various parts of the plant. Such herbicides are therefore able to kill both the shoot and the root. Systemic herbicides may be selective or non-selective. Selectivity is usually based on differences in the ability of the weed and the crop to absorb, translocate and detoxify the herbicide. For example, 2,4-D is a systemic herbicide that kills broad-leaved weeds while sparing grassy weeds or crops. Systemic herbicides are particularly useful in controlling perennial weeds because underground perpetuating organs and roots are killed in addition to the shoot.

Soil-acting herbicides are those which act primarily in the soil. They are usually applied to the soil where they retard or inhibit the germination of weed seeds. Such herbicides usually have long residual action so that they can prevent the growth of weeds for a substantial part of the cropping season. The duration of the residual effect is usually influenced by environmental factors.
The chemical nature of herbicides

Herbicides used for weed control today fall into several chemical groups. A few of them are inorganic, while most of them are organic in nature. Table 9 gives the major chemical groups of herbicides as well as characteristics and examples of each group. Some important herbicides do not belong to any of the major groups listed. These include dalapon which is used extensively to control emerged grasses, and chlornbem which is used for pre-emergence weed control in vegetables.

Table 9  Characteristics and examples of the major groups of herbicides

<table>
<thead>
<tr>
<th>Chemical group</th>
<th>Herbicide characteristics</th>
<th>Examples of particular herbicides</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetamides</td>
<td>Pre-emergence control of grasses. Relatively low persistence</td>
<td>alachlor, diphenamid</td>
</tr>
<tr>
<td>Anilines</td>
<td>Soil acting against grass seeds</td>
<td>trifluralin, nitrilin</td>
</tr>
<tr>
<td>Arsenicals</td>
<td>mostly non-selective</td>
<td>MSMA, sodium arsenite asulam, vernolate, IPC</td>
</tr>
<tr>
<td>Carbamates</td>
<td>Pre-planting or pre-emergence. Volatile ones require soil incorporation</td>
<td></td>
</tr>
<tr>
<td>Phenoxy-compounds</td>
<td>Post-emergence control of broad-leaved weeds</td>
<td>2,4-D, 2,4,5-T, MCPA</td>
</tr>
<tr>
<td>Quaternary ammonium compounds</td>
<td>Contact herbicides</td>
<td>paraquat, diquat</td>
</tr>
<tr>
<td>Substituted ureas</td>
<td>Pre-emergence weed control; most effective before weeds have emerged. High persistence</td>
<td>ametryne, atrazine, simazine</td>
</tr>
</tbody>
</table>

Source: adapted from Kasasian, Weed Control in the Tropics, 1971

Herbicide residues

In the use of herbicides for weed control, consideration should always be given to the possibility of the herbicide being taken up by the crop plant and appearing in the harvested produce. The extent to which this occurs depends on the particular herbicide, the crop species in question, and the time of application of the herbicide. Some crop species may take up the herbicide, but accumulate it in non-harvested organs, or convert it into non-toxic derivatives. Usually before a herbicide is recommended for a particular crop, considerable experimentation is done to determine the extent and nature of the herbicide residues in the crop. The concentration of
residue that is permissible will depend on the level of toxicity of the residue, and the use to which the harvested plant part is to be put. For example, a higher level of residue would be permissible in cotton lint or kenaf fibre, which are not used for food, than in tomatoes or carrots which may be consumed directly.

Conclusion
In practice, the attempt to control weeds in a particular field usually combines the physical, biological and chemical approaches described above. The objective is not to eliminate all weeds from the crop throughout the growing season. Instead, the cost of controlling the weeds must always be weighed against the expected losses due to the weeds. At such periods in its growth cycle when the crop suffers little damage from weeds, it may be more profitable not to incur the cost of controlling the weeds.

Special mention must be made here of the role of general farm sanitation in preventing the spread and establishment of weeds. Such measures include the planting of weed-free seeds, the regular removal of weed seeds from farm equipment and the reduction of run-off from weedy plots.
PART TWO

Practice of Crop Production
10
CEREAL CROPS

Botanically, a cereal is generally defined as a grass grown for its small, edible seed. Cereals are those members of the grass family, the Gramineae, grown for their characteristic fruit, the caryopsis, which has been the most important source of the world’s food for the last 10,000 years. Wheat and barley are the oldest cultivated cereals. Their cultivation started in the Fertile Crescent of Mesopotamia some 10,000 years ago. This region now includes parts of Turkey, Syria, Iraq and Iran. Wheat and barley are the predominant cereals in the warmer temperate climates, oats and rye predominate in the cold temperate regions, while rice, maize, sorghum and the millets are the important cereals of the tropics.

The significance of cereals to modern society is clearly reflected in the importance of cereals in the diet throughout the world. In much of Asia and Africa, cereal products comprise 80% or more of the average diet, in central and western Europe, as much as 50%, and in the United States, between 20 and 25%.

Cereals as a group are the most widely adapted crop species. They can be grown under adverse conditions with at least some yield. This broad range of adaptation, the efficiency of production and the ease with which cereals can be stored make them a dependable source of food.

Cereals can supply sufficient quantities of carbohydrates, proteins, fats, many minerals, and vitamins, but they are not a perfect food because they do not supply the dietary balance required for proper nutrition. Diets that consist primarily of cereals are too high in carbohydrates and deficient in both vitamins and proteins. Recent research has, however, led to the development of cereal cultivars that have more protein of a higher quality. The protein of most cereals is deficient in the essential amino acids lysine and isoleucine. Edible legumes, though deficient in the essential amino acids tryptophan and cystine, are rich in lysine and isoleucine. Thus a diet that includes appropriate mixtures of cereals and legumes can supply all the essential amino acids.
In spite of the fact that cereals do not supply all the proteins and vitamins necessary for a balanced diet, cereal crops will continue to be a major source of food for an expanding world population in the foreseeable future.

The botanical family Gramineae is a very large and specialized family of about 10,000 species. In the modern classification, Gramineae has been divided into six subfamilies. Of the six subfamilies, two, the Bambusoideae (bamboos and their relatives) and the Arundinoideae contain no economically important cereal. The remaining four subfamilies with their economic tribes and species are:

<table>
<thead>
<tr>
<th>Subfamily</th>
<th>Tribe</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Festucoidae</td>
<td>Aveneae</td>
<td><em>Avena sativa</em>, oats</td>
</tr>
<tr>
<td></td>
<td>Triticeae</td>
<td><em>Triticum</em> spp., wheat</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Hordeum vulgare</em>, barley</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Secale cerealis</em>, rye</td>
</tr>
<tr>
<td>The Panicoideae</td>
<td>Paniceae</td>
<td><em>Panicum miliaceum</em>, common millet</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>P. miliare</em>, little millet</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Pennisetum americanum</em>,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Syn. <em>P. typhoides</em>) bulrush</td>
</tr>
<tr>
<td></td>
<td></td>
<td>or pearl millet</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Echinochloa frumentaceae</em>,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Japanese barnyard millet</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Digitaria exilis</em>, hungry grass</td>
</tr>
<tr>
<td></td>
<td>Andropogoneae</td>
<td><em>Sorghum bicolor</em>, sorghum</td>
</tr>
<tr>
<td>The Oryzoideae</td>
<td>Maydeae</td>
<td><em>Zea mays</em>, maize or corn</td>
</tr>
<tr>
<td></td>
<td>Oryzeae</td>
<td><em>Oryza sativa</em>, rice</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>O. glaberrima</em>, African rice</td>
</tr>
<tr>
<td>The Eragrostoideae</td>
<td>Eragrosteeae</td>
<td><em>Eragrostis tef</em>, tef (of Nigeria)</td>
</tr>
<tr>
<td></td>
<td>Chlorideae</td>
<td><em>Eleusine coracane</em>, finger millet</td>
</tr>
</tbody>
</table>
MAIZE

(Zea mays L.)

Maize, also known as corn, is an important grain crop of the world. It ranks second, following wheat, in the world production of cereal crops. The total area devoted to maize in 1948 and 1989 was 88 and 129 million hectares, respectively, i.e. an increase of about 47%. There has been a 240% increase in the production of maize grain during the same period (139 million tonnes in 1948 to 470 million tonnes in 1989). These figures reflect the steep increase in the yields per hectare due to the widespread use of hybrids and improved crop management practices.

Origin and Distribution

Maize is perhaps the most completely domesticated of all the field crops. Wild maize has not been found to date, and there has been much speculation on its origin. There are a number of theories regarding the origin of maize, but it seems most probable that it originated in Mexico or Central America, because this area is considered to be the home of teosinte grass (Euchlaena mexicana, Schrad), a near relative of maize, which shows a wide range of types in this area (Jugenhheimer, 1958).

Probably the first European to see and describe maize was Christopher Columbus. It is most likely that Columbus or some of his contemporaries were the first to introduce maize from Central America to Spain and Portugal. Once established in these two European countries, its passage to the African continent was simply a matter of time and with the Portuguese, its transfer to Asia can be easily envisaged.

Maize has not remained only a crop of the New World, but is now grown on all continents. It is the most widely distributed cereal in the world. Within a comparatively short time from the discovery of America, maize had spread widely throughout the Old World and has now become an important food in many tropical, subtropical and warm temperate countries, including most parts of tropical Africa. In many countries it has almost replaced traditionally grown cereals such as sorghum and millet. The reasons for its popularity are many and include the following:

* it gives one of the highest yields per unit area
* it provides nutrients in a compact form
* its husks give protection against birds and rain
* it is easy to harvest and hull, and does not shatter
* it can be harvested over a long period
* cultivars with different maturing periods are available
* it stores well if properly dried
* it is easily transportable
* consumer preference; many people prefer maize to their indigenous cereals, sorghum and millet.

However, maize is not popular in drier areas which are not climatically suited for its cultivation.

**Area and Production**

The total area sown and production of maize in the world in 1989 were 129.6 million hectares, and 470.3 million tonnes respectively, with an average yield of 3.627 kg/ha. For maize production, the leading country in the world is the USA. About 40% of the world maize crop was produced in the USA. Other important countries for maize are China, the USSR, Brazil, France, Yugoslavia, Romania, Mexico, and India.

The total production of maize in Africa during 1989 was 36.4 million tonnes. The important maize producing countries in tropical Africa are Tanzania, Kenya, Zimbabwe, Zambia, Nigeria, Ethiopia, Malawi, Ghana, Cameroon, Côte d'Ivoire, Mozambique and Zaire.

**Utilization**

Maize has the heaviest usage in Latin America on a per capita consumption basis, but Africa follows closely despite the expanse of drier climatic zones where sorghum and millet are better adapted than maize.

The maize grain contains mainly carbohydrate, but also significant quantities of protein and oil, and a small amount of minerals. The oil is found mainly in the germ (embryo) but also in aleurone

![Diagram](image)

**Fig. 26** Longitudinal section of caryopsis of (A) maize and (B) sorghum
layer of the endosperm (Fig. 29). The carbohydrate is concentrated in the two starchy fractions of the endosperm, i.e. hard starch and soft starch. Protein occurs throughout the grain but is most concentrated in the aleurone layer (Figs. 28 and 29). The minerals are found in the germ and aleurone layers. The composition of the maize seed is approximately 76–88% carbohydrate; 6–15% protein; 4–5.7% fat; and 1.3% minerals. The endosperm protein is deficient in two essential amino acids, lysine and tryptophan, but the germ protein is rich in these two. Thus if the germ protein is also included in the food preparation, the maize is more balanced nutritionally.

Maize is prepared and consumed in a multitude of ways, but most of them can be grouped as follows:

* ground or pounded and boiled
* ground or pounded and baked or fried
* boiled whole
* roasted whole
* fermented.

In Nigeria maize is consumed mainly in two forms: ‘ogi’ and ‘agidi’.

As livestock feed, it is the grain of maize that is of most importance, but the stalks, leaves and immature ears are also used as fodder in some areas.

Maize is industrially important chiefly for the production of starch, oil and alcohol. The starch can be used as such, or converted in dextrins, syrups and sugars. Oil, obtained from the germ, is used to make soaps and glycerine, or is refined for cooking and salad dressing. Maize starch is used extensively for the production of alcohol (beer and whisky) but industrial alcohols (ethyl and butyl alcohol) and acetone can also be derived from maize starch.
Adaptation

Maize has a remarkable adaptability to a wide range of environmental conditions. It is adapted to so wide a range of climates that this plant is now more extensively distributed over the earth than any other cereal crop. It is grown from 48°N to about 40°S latitude all over the world. Similarly, it is grown from below sea level to altitudes of about 4,000 metres.

Maize is a warm-weather crop and is not grown where the mean summer temperature is less than 19°C and where the average night temperature during the summer months falls below 13°C. Most maize is grown where mean summer temperatures vary between 21°C and 27°C. The minimum temperature for germination is 10°C. Germination and especially emergence will be far more rapid and uniform at temperatures above 16°C. At about 20°C, maize usually emerges 5–6 days after sowing. Excessively high temperatures and low air humidity at the time of pollination have adverse effects on pollination and fertilization, causing reduced seed-set. If soil moisture is also low at the time, the exertion of the silks is delayed and seed-set is still further reduced. The critical temperature affecting yields appears to be around 32°C.

The best maize regions are those which receive an annual precipitation of 600 to 1,000 mm, except where the crop is irrigated. More precipitation is generally required in lower latitudes and at low altitudes. Maize is apparently more drought-resistant at the early stage of growth than when fully developed. Severely wilted young maize leaves recover completely while maize subjected to drought at a later stage does not. Stomata in older maize leaves are markedly affected by severe drought lasting a week or more, and do not recover their normal behaviour after a favourable moisture regime is restored, even though the leaves have regained their turgidity and normal appearance. Under irrigation, maize has the highest grain-producing potential of all the grain crops that are grown in dry regions of the low latitudes.

The ideal soil for maize is a deep, medium-textured, well-drained, fertile soil with a high water-holding capacity. Clayey and sandy soils are not very conducive for its growth. However, maize is grown on a wide variety of soils and gives high yields if the crop is well managed. Maize can be grown in soils with a reaction of between pH 5.5 and 8.0, although the optimum range is 5.5 to 7.0. Maize is quite tolerant of salt during germination; increasing salinity delays germination but, up to a point, it has no marked detrimental effect on the percentage emergence (Kaddah and Ghowail, 1964). On the whole, however, maize is considered to be relatively
sensitive to salinity, and is not suited for growing in saline soils or for irrigation with saline water.

**Botanical Description**
Maize is a coarse, annual grass. It belongs to the family Gramineae, tribe Maydeae, genus *Zea* and species *mays*. The root system of the maize plant consists of seminal, secondary or coronal or crown, and

![General morphology of the maize plant](image-url)
aerial or prop roots. The seminal roots, usually 3–5, grow downwards at the time of seed germination. The secondary roots, which are 15–20 times as numerous as the seminal roots, develop from the first few nodes at the base of the stem. The aerial roots grow from the nodes above the ground and help to anchor the plant firmly. Like the secondary roots, these aerial roots also contribute to the uptake of water and nutrients. The roots of the young plant develop rapidly.
Most of the roots of the fully developed plant are found in the soil layer to a depth of 70–75 cm, but single roots may penetrate to a depth of 200 cm and more. Lateral spread under favourable conditions is up to a radius of 100 cm.

The maize stem ranges in height from 0.6–4.5 m and in diameter from 1.4–5.0 cm. The stem consists of 8–21 internodes and a leaf develops at each node. The number of leaves ranges from 8–44. A typical leaf may be 80 cm long and 9–10 cm wide. The leaf blade tapers to a point at the tip. At the base of the leaf, the two edges extend to form two auricles. The sheath clasps the stem (Fig. 30).

Maize is unique among the cereals in the nature of its inflorescence. The maize plant is normally monoecious, i.e. the staminate (male) and pistillate (female) flowers are borne in separate inflorescences on the same plant. The terminal inflorescence or tassel (Fig. 31) is a much-branched panicle that normally bears only male

Fig. 32  Male inflorescence of maize
spikelets, each of which contains two florets with three anthers each (Fig. 32). A single tassel may produce around five million unusually large pollen grains, though the quantity of pollen produced is a cultivar characteristic.

The pistilate flowers are located in spikes and develop near the middle portion of the stem. The mature pistilate inflorescence is called the ear and is borne on a short lateral branch or shank. The pistilate spikelets are borne in pairs in several longitudinal rows (8–30). This paired arrangement explains the customary even number of rows of grain on the ear. Each spikelet contains two florets, of which usually one is fertile. Each floret has a single ovary, terminated by a long style or silk that is covered with fine sticky hairs to which the pollen grains adhere.

The ear is covered and protected by husks which are modified leaf-sheaths. The kernels (grains) are held so tightly to the cob, and covered so tightly by the husks, that maize is no longer capable of dispersing its seeds and therefore cannot survive in nature without man’s intervention. No other cereal is capable of carrying an ear that weighs as much as that of maize. This is mainly possible because the ear is not carried at the top of the stem, as in other cereals, but near, and sometimes below, the middle of the stem. The normal ear of maize contains 8–30 rows of grains while each row bears 20–70 grains. The number of grains in a single ear usually lies between 300 and 1,000.

**Pollination and seed production**
Maize is normally cross-pollinated, being well adapted to wind pollination. About five weeks after tassel initiation, the top internodes elongate rapidly and the tassels emerge. After a few days, the pollen grains are shed. Two or three days later, the silks emerge from the tip of the husk, and start to elongate until they are pollinated. The pollen adheres to the silks with which it comes into contact. Soon the pollen grain germinates and establishes a pollen tube within five to ten minutes after it falls on the silk. The pollen tube enters the central core of a hair on the silk and passes down through the silk. The two sperm nuclei of the pollen grain migrate into the pollen tube and pass down to the embryo sac. Fertilization is accomplished within 15–30 hours after pollination. After pollination, all vegetative growth ceases and the ear grows rapidly to maturity.

**Maize groups**
Several thousand cultivars of maize are now grown throughout the world and they can be allocated to one of seven groups or types,
based largely upon the characteristics of the seed, i.e. endosperm and glume characteristics. These seven groups are listed below:

* *Zea mays indentata* Sturt (dent maize)
* *Zea mays indurata* Sturt (flint maize)
* *Zea mays saccharata* Sturt (sweet corn)
* *Zea mays amylacea* Sturt (soft or flour maize)
* *Zea mays everta* Sturt (pop corn)
* *Zea mays ceratina* Kulash (waxy maize)
* *Zea mays tunicata* Sturt (pod maize).

Most maize cultivars belong to the first two groups, dent and flint maize. The dent cultivars are those with the greatest yield potential; the flint cultivars are better adapted to adverse growing conditions. Plants of the flint type usually exhibit better agronomic characters than the dent types: a high germination percentage, earlier maturity and better tillering capacity are the main features of flint maize.

**Cultivation**

*Cropping systems*
Maize is grown in monoculture or in rotation with other crops. The continuous cropping of maize is successful when high doses of fertilizers are applied and appropriate cultural practices are followed. High yields of maize with the stalks left on the field actually return more organic matter than a rotation with maize. A minimum tillage system and chemical weed control may make it possible to grow maize continuously without destroying tilth. On sandy and silt loams, continuous maize cultivation with high fertilization and reduced tillage may yield an average of 90–100% as high as maize that follows a legume crop in rotation. Continuous maize or row-crops are not as well suited to heavy soils as they are to light soils.

Many farmers prefer to grow maize in rotation with suitable crops. Maize can be grown in one-, two- or three-year rotations with crops such as wheat, grain legumes, groundnuts, potatoes, sugarcane, berseem and tobacco.

Where maize is grown as an irrigated crop, intercropping is generally not practised. Intercropping is adopted where maize is grown as a rain-fed crop, and this is the practice with many traditional farmers in Africa. Under such conditions, one or more crops such as groundnuts, pigeon peas, *Phaseolus* spp., cowpeas, turmeric and ginger can be intercropped with maize. In West Africa, maize is often intercropped with yams, cowpeas, sorghum and melons.
Land preparation
During the last 30 years, the old practice of land preparation to a very fine tilth has changed, especially in advanced countries. We now know that to overwork the soil is not only unnecessary but often harmful. Maize seed needs a soil that is warm, moist, well aerated and only fine enough to give contact between the seed and the soil. Therefore the ideal field for maize is well ploughed, with moderate packing in the row. For this, the land is ploughed with a moldboard plough well in advance of sowing. Then the ploughed land is finally prepared by pulverizing the top 10 cm of the surface so as to provide a soil free from large air spaces. The pulverization should be done immediately before sowing in order to suppress the weeds. Any extra harrowing is of no use to maize. A finely prepared field is not only unnecessary but also more likely to seal over the surface when it rains, causing increasing run-off and erosion. Under traditional farming in tropical Africa, maize is grown on ridges, but it is better to grow it on the flat.

Minimum tillage for field preparation has been more extensively tested and adopted for maize than for any other crop. In particular the distinction between the seed bed, which needs to be firm, and the root bed, which should remain loose for as long as possible, has become an accepted farming practice in the maize-growing regions of the USA. Minimum tillage for maize has generally given yields that were equal to or even greater than those obtained from conventional tillage.

Sowing
The time of sowing is the most critical factor affecting maize yields. Timely sowing, which costs the farmer little or nothing, is the cheapest and most effective step towards ensuring satisfactory maize yields. As a general rule, maize should be sown as near the beginning of the rains as possible. If sowing is delayed there is a decline in the yield of maize. In late-sown maize the early growth is slow because the soil-air-moisture conditions are not ideal (most of the pores are filled with water) and later in the life cycle, late-sown maize may mature or even flower after the end of the rains. This is a serious risk in the short rainy season areas although it is less of a risk where the rainy season is long.

In the parts of West Africa where there are two distinct rainfall peaks, two crops of maize can be grown in a year. The sowing date for early maize is March-April and for late maize August-September. In northern areas with only one rainy season, only one crop of maize is grown, and sowing is done in June.

The seed rate depends on how many plants are to be grown on one hectare. Plant density depends on the fertility status of the soil
(fertile soils support high plant populations), time of sowing (for early or delayed sowings about 5-15% more seed should be sown) and types of maize (hybrid plants are more resistant to lodging and more responsive to fertilizers than the open-pollinated varieties, hence a higher plant density for the hybrids), and the moisture condition (a higher plant population for irrigated crops than rain-fed crops). On an average, 15-20 kg of seed is sown on one hectare of land. For hybrid maize or on fertile soils, the final plant stand may be around 45-55 thousand plants per hectare, and for non-hybrids, 30-35 thousand plants per hectare. Very high seed rates tend to produce weaker stalks with increased lodging and sometimes reduced yields, as well as a larger percentage of barren stalks.

Maize should be sown in rows by drilling. The rows should run across the prevailing slope of the land, following contour levels to retard run-off and minimize soil erosion losses. Inter-row spacings generally vary from 70-100 cm. Seed should be sown at a space of 25-30 cm along the row. In most parts of West Africa, seeds are sown by hand in hills, on ridges or on flat land. Two to three seeds are sown per stand (hole). When seedlings attain a height of 12-15 cm, they are thinned to one or two seedlings per stand.

Maize seeds should not be sown very deep in the soil. Sowing should be done 2-5 cm deep in moist soil. Deeper sowing may prevent the coleoptyle from emerging from the soil. Under dry conditions, however, sowing may be done a little deeper (6-8 cm).

**Fertilization**

The quantity of fertilizer applied to maize by small-scale farmers in tropical Africa is still very low, but the use of fertilizers is increasing. Maize has a high demand for nitrogen, and this is often the limiting nutrient in maize production. The improved hybrids can only reach their fullest expression when they are supplied with adequate nutrients and are grown at high plant densities. In tropical Africa, responses to P are variable and there are only a few responses to K.

The amount of fertilizer to be applied depends mainly on two factors: the projected maize yield that appears attainable in the locality and the fertility level of the soil as determined by soil tests. If the soils are deficient in P and also in K, a dose of 100-150 kg nitrogen (N), 40-50 kg phosphate (P₂O₅) and 80-100 kg potash (K₂O) per hectare must be available to obtain grain yields of 6-7 tonnes per hectare.

To obtain maximum returns from the fertilizer application, fertilizers should be applied in rows, preferably to one side and below the seed, but not in direct contact with it. The placement of fertilizers in rows promotes rapid and uniform growth, especially when the
soil is cool and wet. The application of fertilizers in rows also hastens maturity by a few days. Deep placement of N is more effective in the dry season and surface placement of N is more effective in a very wet period.

The time of maximum nutrient uptake is from 10 days before tasselling to 25–30 days after tasselling. Nitrogen uptake is slow during the first month after sowing, increasing to a maximum during tasselling. Increased nitrogenous fertilizing often increases the protein content of the grain.

A full dose of P and K and a third to half a dose of N may be applied during preparation of the field, i.e. just before sowing, to stimulate early growth. The rest of the N can be applied as a side-dressing when the plants are knee-high, at the period of greatest demand. Before side-dressing N, all the weeds should be removed from the field so that only the maize plants are able to utilize the applied N. Nitrogen on the soil surface will not be effective until rain moves it down into the root zone. It is preferable to side-dress the fertilizer 2–5 cm deep. To avoid root damage, side-dressing of the fertilizer is done between the rows. Nothing will be gained by side-dressing close to the row, since roots meet across the row by the time the crop is knee-high.

Hybrids grown under irrigation with high levels of macronutrients are in many cases causing a depletion of micronutrients at a rate which the soil can no longer make good. In certain cases, the addition of a macronutrient may also be antagonistic to the uptake of one or another micronutrient. For example, Burleson et al. (1961) reported that under certain soil and climatic conditions, phosphorus-induced zinc deficiencies may occur in irrigated maize; this may be due to a P-Zn antagonism within the root. A similar antagonism may occur between K and Mg. Unless there is a clear deficiency of a particular micronutrient in the soil, it should not be applied, otherwise this may very well induce toxic levels of certain micronutrients.

**Water use**

In tropical Africa, maize is mostly grown as a rain-fed crop during the wet season of the year. However, if the aim is to achieve maximum production it is necessary to apply water whenever there is a shortage of rain, as maize has a high water requirement. (The details are discussed in Chapter 6.)

**Weed control**

Inefficient weed control is one of the main factors causing the low average yields of maize in Africa. The period between emergence
and tasselling is the most critical period for weed competition in maize. If maize growth is checked by weeds in its early stages, it never recovers fully.

Weeding is done either with small hand tools or a hand hoe, or by tractor-mounted cultivator. Cultivation controls the weed growth but it also injures the roots of the crop. Chemical methods may also be adopted to control weeds. This can be done either by applying a suitable herbicide in a pre- or post-emergence application, or both. The pre-emergence application of atrazine at 2.0 kg a.i./ha has been found very effective in controlling weeds that germinate in the top 2 cm of the soil. Maize is highly tolerant of this herbicide. Atrazine is also used as an early post-emergence application. A mixture of atrazine with prometryne, ametryne or linuron as a post-emergence application is also very effective in killing the weeds.

In many parts of Africa weeds are controlled by hand weeding. The first weeding is done about three weeks after sowing when the crop is only about 8–10 cm high and two more weedicings are done at equal intervals. The method of weeding used is to hoe upwards from the furrows towards the top of the ridges, so that the soil is heaped up around the plant.

**Harvesting**

The most suitable time to harvest is when the plants attain physiological maturity. A delay in harvesting causes a reduction in the yield. The crop is mature when the kernels reach the hard dough stage. The time of physiological maturity can be accurately determined by the development of the black layer at the point of attachment of the grain to the cob. From this stage onward, ripening consists of moisture loss, which may be quite rapid if the weather is dry. At the time of physiological maturity, the moisture content in the grain averages about 30%. If there is a facility for artificial drying, harvesting should be done as quickly as possible, just after physiological maturity. If no such facility is available, harvesting should be delayed until the crop is dry. At this stage the moisture content of the grain is reduced to 10–12%. Grain with this moisture content can safely be stored just after harvesting and husking.

All over tropical Africa, harvesting is done manually where maize is grown on a small scale. The harvested plants are usually stooked for several days before removing the cobs. In large-scale farming, maize combine harvesting is becoming popular since it involves much less labour. A few days after stooking, the cobs are separated from the plants and then de-husked (i.e. the husks are removed). After de-husking, shelling (the separation of the grains from the cob) is done either by hand, by beating the cobs with a stick or with a
maize sheller. The shelling percentage of maize (the proportion of grain to de-husked cobs) is usually between 70 and 80%.

**Yields**
The average world yield of maize is about 3,600 kg ha, whereas in Africa it is 1,700 kg/ha. The highest average yield of 7,000 kg/ha is obtained in the USA.

**Storage**
Grain is a living embryo and gives off heat, water and CO₂. The rate at which grain lives is governed principally by temperature, moisture content and the availability of oxygen. By adjusting these parameters, grain can be stored for a longer period. This is generally done by drying the grain to a desirable moisture content (11–14%).

The storage of grain calls for protection against damage by insects, mites, moulds, bacteria and heating brought on by the action of bacteria. The most important single factor in the storage of grain is the moisture content, as the activities of harmful organisms are discouraged by low moisture content. Storage is also improved if the grains are free of cracked kernels and foreign matter which provide food for insects and obstruct air movement through the pile of grain. In the tropics the drying of grain is not a problem as it can be dried in the sun and air.

Stored grain should be protected from rain and ground moisture, and the storage container should be rodent-proof, insect-proof and should seal tightly. Steel bins which seal tightly and are easy to clean are best. The earthen bins which are most common in the tropics must be sprayed before use to kill insects. A 2.5% solution of methoxychlor by weight as water suspension or 5% piperonyl butoxide and 0.5% pyrethins by weight as an emulsion, should be applied at the rate of 9 litres per 10 m².

Storing grains or ears of maize in the kitchen is very common in Africa. The ears may be hung under the eaves of the home or from the rafters inside where the heat and smoke from the open fires help to dry the maize and repel insects.

**Crop Protection**
As a general protection against pests and diseases, the following precautionary measures should be taken:

* healthy and treated seed should be sown
* clean cultivation should be adopted, i.e. all the left-over residues from the previous crop should be completely buried in the soil
* any potassium deficiency in the soil should be corrected
* varieties or hybrids resistant to certain diseases and pests should preferably be sown
* suitable crop rotations should be adopted.

**Diseases**

The following are the common diseases of maize. Most of these diseases are serious when the humidity is high.

**Leaf blight**, caused by *Helminthosporium turcicum*: this disease is seldom seen before tasselling time. Boat-shaped, greyish lesions develop in a few days at each infected spot. The lower leaves are infected first and heavily infected leaves may die. The severity of the damage depends on the stage of the plant at which it appears; the younger the plant, the greater will be the reduction in yield. A 60–70% reduction in yield has been found. The most practical method of control is to avoid infection by adopting the above general precautionary measures. When these are not effective, partial control is possible by spraying with an appropriate fungicide.

**Rust**: maize is susceptible to three rust diseases, of which common rust (*Puccinia sorghi*) is the most widespread. This disease is characterized by the appearance of brown to black powdery pustules on both sides of the leaves. The spores are carried by the wind, and they germinate on, and penetrate into, the leaves. Common rust does not usually cause heavy damage to early-sown maize. However, late-sown crops may be attacked severely. Resistant cultivars should be grown where the disease is prevalent.

**Smut**: maize is attacked by two types of smut, common smut caused by the fungus *Ustilago maydis* and head smut caused by *Sphaecelotheca reiliana*. Smut is first seen as a greyish lump which may grow to considerable size. When the fungus spores are mature, the lump turns black and releases the spores as it bursts open. All the parts of the plant above the ground, i.e. stalk, leaves, tassel and ear, are attacked by this disease. It is often more prevalent in drought years or where there are many barren stalks. There is no common control measure, but most hybrids are fairly resistant.

**Root rots** are caused by *Diplodia*, *Gibberella* and other fungus parasites and may lead to high plant mortality. Affected plants tend to lodge. Root rots occur frequently in compacted, poorly-drained soils. They can be controlled by the use of resistant varieties or by the chemical treatment of seeds before sowing.

**Stem rots** are also caused by *Gibberella* and *Diplodia* fungi. *Gibberella* stem rot usually causes plants to break at the joints while *Diplodia* infection more often caused breakage between joints. When stem rots infect the maize plants in the early stage of growth, they cause small ears with shrunken kernels. They increase stem breakage and harvest losses whether they infect the plants early or
late. Resistant hybrids should be planted and harvesting should be done early to avoid losses by lodging.

**Ear rot** is a very common and frequently destructive disease. The spores are wind-borne and are trapped between the husks of the ear. When moisture conditions are favourable, they penetrate into the developing ear, on which a greyish-white mould develops. The rot starts at the base of the ear and progresses towards the tip. Early infection may result in the complete destruction of the ear. Seed treatment, crop rotation and the growing of resistant cultivars may reduce the infection.

**Insect pests**

Serious insect pests include rootworms, cutworms, armyworms, earworms, stem-borers, maize-borers, leafhoppers and grasshoppers. Soil insect pests such as wireworms, rootworms, white grubs, ants and other soil-inhabiting insects may cause considerable damage to the germinating seeds and the emerging seedlings. These can be controlled by spraying with aldrin or heptachlor.

**Rootworms** such as *Diabrotica* spp. periodically cause serious damage to maize, especially when the crop is grown continuously. Crop rotation minimizes the incidence, and they can also be controlled by spraying with aldrin or heptachlor.

**Cutworms**: several species of cutworm attack maize. The moth lays clusters of white eggs in moist sites near a potential food supply. The small larvae feed on the leaves, but when they become larger they attack the young seedlings, cutting the stem just below the ground. In severe form, they completely sever young plants and eat out the centre of the stem. Plants of up to 100 cm may suddenly wilt and die. During the day cutworms stay in the soil within 5–6 cm from the plant at about 5–8 cm deep. Infestation generally starts in the low spots in the field and may spread to other areas. When plants are cut above the growing point they recover although the yield will be reduced. At present there is no effective control measure. The severity of an infestation can be minimized by applying endosulfan.

**Stem-borers** (*Sesamia cretica*): in young plants, the larvae bore into the whorl and cause cessation of the growth of the maize stem. In more developed plants the larvae do not prevent growth but at a later stage the larvae also attack the ear. Repeated applications of granular pesticides to the whorl have been found to be effective. Cultural control consists of ploughing down all plant residues to a sufficient depth.

**Leafhoppers** (*Empoasca lycica*) attack the young maize plant. If no effort is made to control the infestation, fully-grown plants may also be attacked. They can be controlled with parathion.
Grasshoppers: many species of grasshopper feed on maize. Normally they eat only the leaves but when they are numerous they may also destroy part of the stem and ears. There are many natural enemies of grasshoppers. When infestations assume serious proportions, insecticides such as malathion and diazinon can be used.

Earworms (*Heliothis armigera*): the larvae first feed in the whorl of the young plants and later in the developing tassels. After the silks dry out, the larvae enter through the ear tip and the developing kernels are attacked. Severe infestation may cause yield losses of up to 50%. Chemical control with carbaryl, applied at the ear zone, can be effective, but is not economical.
SORGHUM
(Sorghum bicolor (L.) Moench)

Other common names for sorghum include: great millet, guinea corn in West Africa, durra in the Sudan, mtama in East Africa, jowal, jola and cholam in India, milo and sorgo in the United states, and koaliang in China.

Sorghum is the fifth most important world cereal, following wheat, maize, rice and barley. It is a staple food in the drier parts of tropical Africa, India and China. Sorghum, because of its drought resistance, is the crop of choice for dry regions and areas with unreliable rainfall. In recent years, maize has tended to replace sorghum in many parts of tropical Africa, mainly in East and Central Africa. The reasons are described in the section above on maize. To save sorghum from extinction, breeding work must be intensified to evolve cultivars which can compete with maize.

Origin and Distribution
Many annual and perennial species of sorghum are found in the wild form. The greatest variation in the genus is found in the north-east quadrant of Africa, north of latitude 10°N and east of longitude 25°E. The crop probably originated here. Snowden (1955) has reported that out of 16 species, 14 are found in this quadrant of Africa, which must be the centre of origin and diversification. It is believed that a form (or forms) was domesticated in the Ethiopian region some 5,000 or more years ago to produce Sorghum bicolor. The cultivated and wild forms were then spread by man throughout Africa.

Sorghum was taken from eastern Africa to India, probably during the first millennium BC and from there to China. Sorghum then spread to the Mediterranean countries. The crop was introduced to the United States from Africa in about the middle of the nineteenth century. It was grown along the Atlantic coast and then carried westward to the drier regions.

Area and Production
The total area sown and production of sorghum in the world in 1989 were 44.4 million hectares and 58 million tonnes, respectively. The leading countries in sorghum production are the USA, India, China, Nigeria, Mexico, Sudan and Australia. The total area sown and production of sorghum in Africa in 1989 were 17 million hectares and 14 million tonnes, respectively. The important countries for sorghum in tropical Africa are Nigeria, Sudan, Ethiopia, Burkina Faso, Tanzania, Niger, Uganda and Ghana.
Utilization
The air-dried whole grain contains approximately 8–16% water, 68–74% carbohydrate, 8–15% protein, 2–5% fat, 1–3% fibre and 1.5–2.0% ash. Sorghum is used in many ways. It is used as a staple food, for brewing beer, as a livestock feed, for manufacturing industrial goods, as fuel, and in many other forms.

For food, the white grains are preferred to the red, giving a more attractive flour. In Africa, when sorghum is cooked as a staple food, the dry grains are usually ground, either alone or with other cereals, cassava chips or dried sweet potatoes. The flour is made into a thin porridge or a thick paste or dough by boiling in water. The grains of many cultivars have a dark nucellar layer which gives a sour, bitter flour of a dark and unattractive colour. Softer, sweeter-grained cultivars are cooked and eaten whole, those which are cut before ripening because of shedding being used as rice. In Africa, sorghum is widely used for brewing beer. The beer contains 2–10% alcohol. Sorghums, often called sorgos, with large juicy sweet stems are used for chewing and the manufacture of syrup. Sorghum grains of especially the red cultivars are used as livestock feed. Smaller-seeded sorghum cultivars are used for poultry feed, either whole or cracked.

The sorghum plants are used as fodder, forage or silage. One must be very careful with this, however, as it is dangerous to feed the leaves and stems of poor drought-stricken plants to young stock as they may contain the poisonous glucoside ‘dhurrin’. Tillers produced after harvesting are also very poisonous. The poison is present from germination, increasing to a maximum, and then disappearing as the grain develops, so that in the later stages the plant is safe as fodder. On hydrolysis, the glucoside yields hydrocyanic acid, HCN.

Sorghum grain is used in the manufacture of such items as wax, starch, alcohol, dextrose sugar, edible oil and gluten feed. In addition it is used to manufacture gypsum lath, paper and cloth sizing, and adhesives. Dried sorghum plants have many domestic uses such as for making baskets and mats, as fencing or for thatching houses. They are also used as fuel or as mulch.

Adaptation
Sorghum is adapted to a wide range of ecological conditions and can be grown under conditions which are unfavourable for most of the cereals. It is essentially a plant of hot and warm countries. Sorghum withstands extreme heat better than other crops. It can tolerate hot and dry conditions but can also be grown in areas of high rainfall. It is, however, killed by frost.
Sorghum is grown between 40°N and 40°S of the equator. The crop is most extensively cultivated in the drier savannas and grasslands of tropical Africa, the plains of India, and the southern great plains of the USA. In tropical Africa, its cultivation is restricted to savanna zones.

Although sorghum is a crop of the plains, it is grown even up to an elevation of 2,400 m in the Kigezi Highlands in Uganda. Most East African sorghum is grown between the altitudes of 900 and 1,500 m. The optimum temperature during the growing season ranges from 27–32°C. The minimum and maximum temperatures for growth are 15°C and 40°C. Extremely high temperatures during the grain formation period reduce the seed yield.

Sorghum is well adapted and widely grown where the annual rainfall varies from 400 to 700 mm. Its cultivation is limited to tracts with a rainfall of about 1,000 mm as maximum. Its great merit is its drought resistance. Its xerophytic character permits it to survive physiological drought produced by waterlogging where root functions are temporarily impaired.

The drought resistance of sorghum is due to the following morphological and physiological properties:

* the leaves and stems are covered by a waxy material that reduces water losses
* losses of water from transpiration are also reduced because of the relatively small leaf surface
* the plants are able to remain dormant during hot, dry periods and then grow again when conditions are favourable.

Sorghum is grown successfully on many types of soils, except for rough, stony or gravelly soils. In the wet season the highest yields are obtained on heavy soils, but in the dry season it does best on sandy soils. It can be grown with a wide range of soil pH from 5.0 to 8.5 and tolerates salinity better than maize. It can be grown on soils too poor for many other crops.

**Botanical Description**
Sorghum belongs to the family Gramineae, tribe Andropogoneae and subtribe Sorghastrae. This subtribe has two genera: *Cleistachne* Benth, with four species in southern Africa and India; and *Sorghum*, which has a wide distribution throughout the warmer regions of the world.

Sorghum is often an annual with a single stem varying in height from 1–5 m. Tillers come out in some cultivars when they are grown as a ratoon crop. First a single main root is produced from which a large number of much-branched lateral roots are produced. Many
adventitious fibrous roots are formed from the lowest nodes of the stem. The stem is usually erect, dry or juicy, insipid or sweet, grooved and nearly oval. The peduncle (top internode) is not grooved. Young sorghum plants can be distinguished readily from maize plants because of the saw-tooth margins of sorghum leaves. Crown buds give rise to tillers. The leaves are alternate in two ranks; the leaf sheaths are 15–55 cm long and encircle the stem. The midrib is prominent.
The sorghum inflorescence (Fig. 33) is a loose to dense panicle, usually erect, having many primary branches bearing paired spikelets. The sessile spikelet of each pair is perfect and fertile, while the pedicellate spikelet is either sterile or staminate. There are two florets in the fertile spikelet, the lower sterile and the upper fertile. Sorghum is about 95% self-pollinating.

A well-developed panicle may contain as many as 2,000 seeds. The seeds are roundish, ovoid to flat, and can be white, pink, red, yellow or brownish. Mature seeds (like those of maize) have a black spot near the base. Immature seeds develop the black spot after drying. White or yellow seed grain types are generally preferred for food; red, pink or brown pigmentation makes the grains 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.

Cultivation

Cropping systems
Sorghum follows other crops readily in rotation, but care should be taken in the choice of crop to follow sorghum, as sorghum greatly impoverishes the soil. Generally the yield of a crop grown after sorghum is much lower. The depressing effect of sorghum is least noticeable in legumes and most pronounced with cereals. Sorghum injury to subsequent crops under irrigation, where soil moisture is ample, has been attributed to the high sugar content of sorghum roots and stubble. These sugars furnish the energy for soil microorganisms which multiply and compete with the crop plant for the available nitrogen in the soil and thus retard crop growth. This condition lasts only for a few months, or until the sorghum residues have decayed. The injurious effect of sorghum on irrigated land may be overcome by nitrogenous fertilizers, farmyard manure or green manuring. The detrimental influence of sorghum on dry land may be avoided by fallowing the next season.

The frequent growing of sorghum on the same land in Africa often leads to a build-up of the parasitic Striga weed population which may make further cultivation of the crop impossible. In Africa, sorghum is usually grown after groundnuts, finger millet or cotton. It is often intercropped with other crops. In West Africa it is often grown with bulrush millet on ridges. Intercropping cowpeas with sorghum adds nitrogen to the field. In East Africa the most common practice is to interplant it with other cereals, pulses, sesame or sweet potatoes. In Uganda it is mainly grown with finger millet.

Land preparation
Sorghum is grown in both wet and dry seasons. It is usually grown as a rain-fed crop, but also under irrigated conditions. Sowing is
either done on flat land or on ridges. The land is prepared in different ways for flat and ridge sowing. Under irrigated conditions and for flat sowing, the field should be well-levelled and a fine seed bed, free of weeds and crop residues, is desirable. An uneven and cloddy seed bed leads to an uneven stand, but broadcasting a liberal quantity of seed, followed by thinning, will help to compensate for this. In most parts of Africa, sorghum is sown on ridges. If it is sown in the same field in which it was grown in the previous year, the old ridges are destroyed and new ones are made in the old furrows.

**Sowing**

Sorghum is subject to the smut disease, which in some areas appears every year and sometimes in severe form. To control this disease, seed should be treated with chemicals before sowing. One packet of Aldrex T or Fernasan D should be thoroughly mixed with 3 kg seed in a container. Seed treatment should take place just before sowing. Seeds can also be treated with Agrofan GN, thiram, captan and carbofuran. The pre-soaking of seeds before sowing for about 24 hours at ambient temperature gives higher yields.

The time of sowing has a marked effect on the yield of sorghum. The time of sowing is governed to some extent by the time taken to maturity, but in dry climates the crop should be sown with the first onset of rains, as delay can result in substantial losses in yield.

In Nigeria and other West African countries, sorghum is sown in the savanna (lying in the seasonal climate zone) comprising four agro-climatic regions: southern Guinea, northern Guinea, the Sudan and the Sahel (Fig. 9). Since the time of the onset of rain is not the same in these four zones, the time of sowing is different. Rains are earliest and of the longest duration in the southern Guinea savanna and the latest and shortest in the Sahel zone. It is very difficult to predict when the rain will start. It varies from year to year and from place to place. The unpredictable behaviour of rain makes it difficult to recommend the exact time of sowing sorghum in different parts of the country. The only generalized recommendation that one can make is that sowing should be done as soon as the rains are established. Any delay in sowing thereafter will result in a decrease in yield.

In the southern Guinea savanna, where the duration of the rain is very long (from mid-April to November), sowing too early may result in the harvesting of the crop during the rains. Even though good yields may be obtained, the problem of mouldy heads will be intensified. Such grain will not store well and as a result the produce will be of low quality. To overcome this problem, late sowing may
be recommended. One may sow a short duration crop of maize before sowing sorghum.

In the northern Guinea savanna, the rains are generally established about mid-May and end in September. The duration of rainfall is just adequate for a long season sorghum crop without it having to mature in the rains. Several years' data are available to show that delayed sowing after the rains are established can cause up to 40% reduction in yield. In one particular study in Samaru (Nigeria), there was an average of 40 kg/ha loss in yield for each day if sowing was delayed beyond the optimum sowing period (second week of May).

The proper time of sowing is even more critical in both the Sudan and Sahel ecological zones, where the effective rainy period is reduced to 100–120 days (mid-June to mid-September). There can be a total loss of crop in these zones if there is more than two weeks' delay in sowing. In the Sudan zone, sowing later than mid-July can result in total crop failure and in the Sahel zone sowing could be as late as late July because of the late arrival of rains and for these regions early maturing or short season cultivars are recommended (Egharevba, 1979).

As sorghum is sown under varying conditions, there is great variation in seed rate. In Nigeria and other African countries where 3–5 seeds or a pinch of seeds are sown in each hill on well-prepared ridges, the seed rate is usually 10–14 kg per hectare. In the flat method of sowing where two seeds are sown in each hole, a seed-rate of 3–5 kg/ha is used.

The optimum plant population depends upon the size of the cultivars, the amount of moisture available, the fertility status of the soil, and the number of crops grown together. If a row of sorghum is alternated with a row of millet or cowpeas, there will be wider row spacing.

An optimum plant population is essential for good yields of a crop. Unfortunately, the farmers in Africa sow the crop at too wide a spacing, i.e. 90 × 20–60 cm, which gives a plant density of about 18,000 per hectare against the recommended population of about 50,000. This is one of the main reasons for poor yields. Depending on the location within the savanna zones, the plant population should range from 30,000 plants per hectare in the Sahel zone to 60,000 plants per hectare in the southern Guinea zone. Sowing at 70–75 × 25–30 cm will give about 50,000 plants per hectare.

In some Asian countries, sorghum is sown at very close spacing to have very high plant populations: for the tall cultivars, 60,000–180,000 plants per hectare and for the hybrids 150,000–250,000 plants per hectare. Higher plant populations per unit area not only
help in obtaining more yields but also provides a good canopy to the land to check the run-off of water and erosion of soil. In a field trial in 1972–4 in Temple, Texas (USA), Adams et al. (1978) studied the effect of narrow (50 cm) and conventional (100 cm) row spacings of sorghum plants on run-off and erosion. In narrow rows a more complete plant canopy was established earlier and provided more ground cover for much of the growing season. Canopy cover was at a maximum 63 days after seedling emergence and provided a ground cover of 46 and 81% for conventional and narrow spaced rows, respectively.

Sorghum can be sown by broadcasting, drilling, or sowing in furrows or ridges. Sowing in furrows implies sowing behind the plough. In East Africa, broadcasting is the most common method of sowing but in most of the countries of West Africa the general practice is to sow sorghum on ridges. The flat method of sowing is practised in a limited area. Experimental results to date show that sowing on ridges has no special advantages over sowing on flat fields. However, sowing on ridges is favoured in Nigeria and other countries of Africa for the following reasons:

* the problem and danger of waterlogging in poorly drained areas is reduced by sowing on ridges
* some of the cultural operations are easier on ridges; for example, it is easier to hoe weeds on ridges than on the flat
* in small-holdings it is easier to make ridges with the type of equipment available than to plough and level a comparable area
* erosion control is improved when ridges are made across the slope.

Sorghum seed should be sown at a depth of 2.5–3.0 cm. In tropical Africa, where the ridge method of sowing is common, 3–5 seeds are sown per stand at a depth of about 2.5 cm. After sowing the soil is firmed over the seed by pressing.

**Fertilization**

Sorghum has been found to respond well to added fertilizers. The fertilizer requirements and practices vary widely between countries, depending on local climate, the fertility status of the soil, the economic conditions of the farmer, whether or not the crop is irrigated, and the cultivar sown. Indigenous long season sorghum cultivars are well adapted to poor soils under low plant densities, but lack the genetic potential for rapid growth and the efficient utilization of available light and water in fertile soils. Improved dwarf and semi-dwarf cultivars give very high yields with adequate
fertilization and better crop management. The fertilization of improved sorghum cultivars should take into consideration how much of the various nutrients is removed by a normal crop. For a grain yield of 3,000 kg/ha with a grain stover ratio of 0.36, sorghum removes 102 kg N, 46 kg P₂O₅, and 140 kg K₂O from one hectare of land. K is mostly removed by the stover (126 kg/ha).

On the basis of experiments carried out in the northern parts of Nigeria, Balasubramanian and Mokwunye (1978) have recommended 100 kg N/ha split in two doses, half at sowing and half six weeks after sowing where sorghum is grown after a short fallow period or a non-legume. For sorghum following a good crop of groundnuts or a similar legume, they have recommended an application of 40–50 kg N/ha as a single top dressing 4–6 weeks after sowing. For a sorghum-millet mixture they also recommend 100 kg N/ha. Urea or nitroshell is recommended as a source of N and both should be well incorporated into the soil to achieve maximum efficiency. Too much nitrogen always depresses sorghum grain yields due to excessive vegetative growth and stover yield, particularly with tall, long-season cultivars.

The response of sorghum to high P application is very variable and not encouraging. As suggested by Thompson (1975), it is highly likely that sorghum roots use available sub-soil P or enough surface P is made available during the long growing season to meet the crop requirement. Balasubramanian and Mokwunye (1978) have recommended an application of 40 kg P₂O₅/ha for the savanna soils of Nigeria as they are very poor in native P.

The trials carried out in the savanna in Nigeria from 1972–75 clearly demonstrate that savanna soils respond very well to K application, as the soil K is fast depleted with continuous cropping. Sorghum stover is very high in K and the method of crop residue disposal will determine the amount of K returned to the soil. Wherever the stover is incorporated into the soil either as such or as ash after burning, a major portion of the K taken up by the crop is restored to the soil. K fertilization in such circumstances should take into account this recycling of K through residue disposal. Excess application of K will also decrease crop yields due to cation imbalance in the soil (Jones and Stockinger, 1976). The full benefit of N fertilization will be achieved only in the presence of adequate K (Heathcote, 1973). For the present yield and crop management levels, 30 kg K₂O/ha is recommended to obtain good sorghum yields. Unlike P, K is highly mobile in savanna soils, particularly in the coarse-textured ones. Previously applied K may therefore have been moved out of the root zone and direct K application to each crop is essential to obtain high efficiency of applied fertilizers.
The following method of fertilizer application has been recommended where sorghum is grown on ridges. Half the recommended dose of N should be applied either at the time of sowing in the same row, but below the seed level, or in holes (or rings) 7–8 cm away from the stands, two or three weeks after sowing; the other half should be applied by the placement method four to six weeks after the first dose. The full dose of P and K fertilizers should be applied to the old furrow bottoms before re-ridging, if ridges already exist; if ridges do not exist, the full dose should be placed in holes 7–8 cm away from the stands not later than one week after germination. Where sowing is done in a levelled field, the full dose of P and K and half the dose of N may be applied at the time of sowing.

**Water use**

Of all the climatic factors which influence the pattern and productivity of rain-fed agriculture, the availability of water to crops is by far the most important. Although sorghum is tolerant to drought because of its ability to remain dormant during a drought period and then grow fast again afterwards, it has been found responsive to good water supply. Under ideal soil conditions sorghum has an extensive and deep fibrous root system. The deep rooting system is of tremendous advantage in extracting water from deep in the soil. As these roots are not yet developed or established at the seedling stage of growth, it is important to maintain adequate surface moisture at this time. In addition to the seedling stage, the pre-flowering, flowering and grain formation stages have been found critical for water demand.

**Weed control**

The control of weeds in important in the early stages but when sorghum has become well established it can tolerate weeds better than most crops. Weeding is usually done by hand in Africa. Two well-timed weedings are enough. After removing the weeds the ridges should be remolded.

Both mechanical and chemical methods of weed control are being tried to eventually replace the laborious hand hoeing. To date atrazine at 1.0–1.5 kg a.i./ha or a mixture of atrazine/metolachlor or atrazine/alachlor in equal proportions at 2 kg/ha have given very good weed control.

The parasitic striga is the most serious weed and should be removed before it sets seeds. The minute seeds of striga are produced in enormous numbers and can remain viable in the soil for many years, particularly under dry conditions. The seeds can only germinate when stimulated by a substance from the host root and must not be more than 1 cm away from it. The radicle attaches itself
to the host root by a haustorium, which penetrates to the vascular system. Further haustoria are produced by the secondary roots. The parasite remains below ground for 3–6 weeks, during which time it is entirely dependent upon the host for its nutrition. Some plants then appear above ground, produce chlorophyll and photosynthesize, but are still dependent upon the host for water and minerals. Flowering commences 10–12 days after emergence. In general, ripe striga seeds are produced 90–120 days after planting the crop.
Symptoms of severe striga attack resemble drought, i.e. the leaves wilt and turn yellow and plants remain stunted and may die before setting seed. Partial control may be possible by including some legumes in the rotation for several years. Nitrogenous fertilizing often reduces striga attacks. Spot spraying with ametryne and atrazine has given good results at Samaru in Nigeria. Careful weeding of striga before flowering or fruiting will help reduce infestations. All striga plants should be pulled up before seed is set. At Samaru (Nigeria) efforts are under way to develop varieties that are resistant to striga, since this is the most feasible means of control. Resistance may be due to mechanical or physiological obstruction to the penetration of the haustoria or the low production of the stimulant which causes the seeds to germinate.

Harvesting and threshing
Harvesting should be done when the grains are fully mature and dry. The time to maturity varies greatly among cultivars, some early types taking only 100 days, while late ones take 120–130 days. Some cultivars may be ratooned to produce a second crop. Timely harvesting is necessary for optimum results. Generally, harvesting should be done when the moisture content of the grain is below 14%.

There are two methods of harvesting. The first involves cutting down the entire plant with the head. The plants are staked up with the head exposed to sunlight for drying. After drying to the required moisture content, the heads are removed for threshing and processing. The second method involves cutting the heads from the stalks and then drying them to the required moisture content before threshing. The former method is favoured over the latter especially where the tall varieties are grown. When the heads are thoroughly dried, they are threshed by beating them with heavy sticks or flails.

Yields
Yields of threshed grain vary widely depending upon the cultivar and the location. In Africa yields vary between 300–1,200 kg/ha, with an average of about 750 kg/ha for rain-fed sorghum. Irrigated
sorghum yields about 2,000 kg/ha. In Samaru (Nigeria) in experimental plots, yields of up to 4,000 kg/ha have been obtained. There is much scope for yield improvement in this crop. The percentage of grain to head is 70–80%.

Storage
For safe storage, the moisture content of the grain should not exceed 12%, but even at this level the grain may be spoiled if it is mixed with broken pieces of stems and leaves, which usually contain more moisture than the grain. This will cause heating and moulding. Sorghum that is to be kept for six months or longer should be treated with Gammain A and so as to control storage insect pests. All the storage structures and containers should be cleaned and treated with an effective insecticide before storing the grain.

Crop Protection

Diseases

Seed and seedling diseases: at relatively low soil temperatures, various fungi of the genera *Aspergillus*, *Rhizoctonia*, *Penicillium* and others, attack and destroy the germinating seeds. Other species, such as *Pythium* and *Fusarium* attack and kill the seedlings or retard germination. The use of sound seed and appropriate seed treatment will provide satisfactory control.

Root and stalk diseases: root-rot is caused by *Pythium arrhenomanes*. The disease causes stunting of the plants and their early death. Only resistant cultivars should be grown in infected soils. Several rots, of which the principal ones are red rot (*Colletotrichum graminicolum*), charcoal rot (*Machrhopoma phascoli*) and fusarium rot (*Gibberella fujikuroi*) damage the stalk. The fungi invade the stalk, causing lodging or the premature ripening of the heads. No practical control measures have been developed for preventing root and stalk rots; sowing resistant cultivars is the only effective way to avoid losses.

Leaf diseases of sorghum may be caused by various bacteria or fungi, or be due to physiological disturbances. Some of the more important fungal leaf diseases of sorghum are leaf blight (*Helminthosporium turcicum*), leaf spot (*Phoma insidiosa*) and rust (*Puccinia purpurea*). Many of the leaf diseases may be partially controlled by crop sanitation (destruction of crop residues, alternative host plants and volunteer sorghum seedlings) and crop rotation. For pathogens borne on the seed surface, seed treatment should be undertaken.

Panicle diseases: the principal diseases attacking the sorghum panicle are the smuts. In smutted panicles, the kernels are replaced
by small galls, and the entire head is usually destroyed. The three main types of smut occurring on sorghum are:

* covered-kernel smut (*Sphacelotheca sorghi*), in which the galls are contained in a thin membrane which usually persists until threshing. This is the most serious smut disease, and occurs in all regions where sorghum is grown.

* loose-kernel smut (*Sphacelotheca cruenta*) in which the thin membrane covering the galls usually breaks as soon as they reach full size.

* head smut (*Sphacelotheca reiliane*) which transforms the entire head into a mass of brown spores.

Covered and loose smuts are externally seed-borne and can easily be controlled by dressing the seed with fungicides such as Aldrex T (aldrin and thiram) and Fernasan D (thiram). Head smut is soil-borne and the most effective method of control is by the development of resistant cultivars. The removal and destruction of the entire head before the galls burst is an important sanitary measure.

**Insect pests**

The major insect pests of sorghum are shootflies, stem-borers and sorghum midges.

**Shootflies** (*Atherigona soccata* Rondani) lay their eggs on the leaves of young plants. The larvae penetrate into the culm and generally destroy the growing point. These flies can cause a yield reduction of up to 70%. Early planting is the easiest means of control. Systemic insecticides such as Thimet (phorate), Basudin (diazinon) and Furadan (carbofuran), applied to the soil and taken up by the plants, have been found effective against shootfly in Samaru (Nigeria).

**Stem-borers** (*Busseola fusca, Sesamia calamistis*): in Nigeria, these cause damage in the rainy and dry seasons, respectively. These pests bore holes in the stalks where they may cause sufficient damage to prevent earing. At a later stage, mature ears may break off before harvesting. Sanitary measures such as the destruction of infested stalks are the only effective control measure.

**Sorghum midges** (*Gontarina sorghicola*) attack the sorghum heads. The larvae feed on the ovary and cause it to shrivel up without forming grain. Early planting so that flowering is completed before the adult midge population reaches damaging levels is an effective control measure. Plant breeding for resistant cultivars offers the best long-term control. Several cultivars have been screened at Samaru and promising ones are being further studied. Jotwani et al. (1977) reported from India that spraying or dusting
with carboprophenthothion and endosulfan, or spraying with chloropyrifos and BHC (lindane) dust were the most effective.

**Other pests**

By far the most serious sorghum pest in Africa is the small red-billed weaver, or black-faced dioch belonging to the species *Quelea quelea* (L). The population is very high in Africa. They roost and nest communally, usually on different sites. They nest in thorny trees, usually *Acacia* spp. and one tree may hold 100–2,000 of their woven hanging nests. They invade the crop like locusts and cause heavy damage.

Other species of birds such as *Lamprotornis* spp., *Passor* and *Aloceus cucullatus* also cause damage. Most damage occurs from the heading stage onwards but there is a sudden increase when the grain passes from the dough to the mature stage.

Attacking the birds in their nesting and roosting sites provides the most effective method of control. Toxic chemicals, sprayed from aircraft at dusk, has been found cheap and effective. From Puerto Rico, Sotomayor-Rios (1977) reported that when methiocarb was applied to panicles at the rate of 2–4 kg/ha, either at 1, 2, 3 or 4 week intervals, birds caused less damage than in the control plot. The use of chemicals did not affect yields, threshing percentage or weight of panicles.
MILLET

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

* major food species: *Pennisetum typhoides* – Bulrush millet, Pearl millet or Bajra
  *Eleusine coracana* – Finger millet, Ragi or Marua
* lesser food species: *Setaria italica* – Foxtail millet;
  *Panicum miliaceum* – Proso millet or common millet
  *Echinochloa crusgalli* – Japanese millet, var. *frumentacea*
  *Panicum ramosum* – Browntop millet
  *Paspalum scrobiculatum* – Kodo millet

In general, the millets are 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 with adequate rainfall for crop growth is short (three to five 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 drought. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) was established at Hyderabad, India, to provide worldwide research and training on important millets.

Millet grains are high in starchy components (55–65%) and thus serve as an energy food. The content and quality of protein differ greatly among the various types of millet, but they are all deficient in some nutritionally essential amino acids. However, the seeds are usually small and the germ (which is rich in protein) is not separated from the rest of the seed so that the full dietary value is retained in foods made from millet. The seed of bulrush millet is larger than that of the other millets.

Area and Production
The area and production of millet in the world in 1989 were 37.5 million hectares and 30.5 million tonnes, respectively. The area and production of millet in Africa in the same year were 14.3 million hectares and 9.3 million tonnes, respectively. Bulrush millet has the greatest use in Africa and India, and finger millet in India and parts of East and Central Africa. The total production of millet in Asia and Africa is somewhat smaller than for sorghum, but in some sub-humid environments millet is the dominant cereal.

The important countries for millet production are India, China, the USSR and Nigeria. Other countries in tropical Africa where
millet production is important are Burkina Faso, Senegal, Chad, Uganda, Sudan, Mali and Niger.

**BULRUSH MILLET** (*Pennisetum typhoides* (Burm. f.) Stapf and Hubbard)
There are many species of *Pennisetum* grown in different countries of tropical Africa, especially in West Africa. Among them *P. typhoides* is grown on the largest area. It is the main millet crop of East Africa and Nigeria. Bulrush millet is often called pearl millet. Among the cereals, it is the crop of the driest region. It is very drought resistant and gives reasonable yields on infertile sandy soils which would be unsuitable for other important cereals. Despite these advantages, it has declined in importance all over Africa except in very dry areas. It has been replaced by maize and sorghum. Although bulrush millet is not as important as other cereals when world production figures are considered, it is the basic diet of several million human beings in Africa and India.

**Origin and Distribution**
There seems little doubt that tropical north Africa is the home of cultivated *Pennisetum*. It probably originated in the semi-arid savanna (Sahel zone) of Africa, where many of the wild relatives are now to be found. There is no general agreement on whether the crop was domesticated in West Africa or in Ethiopia, or whether it had a diffuse origin at more or less the same time in several parts of the savanna zone. The early dispersal of the crop was most likely associated with that of sorghum and both reached India together from East Africa, possibly at least 2,000 years ago. Millet provided a useful cereal in the drier areas. Bulrush millet first became known in Europe in the second half of the sixteenth century, when plants were grown in Belgium from the seeds brought from India. Although bulrush millet has been widely introduced throughout the tropics and subtropics, it has achieved little importance outside Africa and India.

**Utilization**
Bulrush millet is the staple food of millions in the drier parts of tropical Africa. The air dried grains contain approximately 12.4% water, 11.6% protein, 5.0% fat, 67.1% carbohydrate, 1.2% fibre and 2.7% ash. The protein content varies from 8.8–16.1%, but it is low in lysine and methionine. The nutritive value is comparable to that of rice and wheat.

After husking, the grains may be cooked like rice, or they may be ground into flour to make porridge, cake or bread. The grains are
also used to produce malt, and in Africa the malted seed is an important source of beer. For brewing, the grains are germinated, dried, ground into flour and then boiled in much water. This is then allowed to ferment for about a week.

The grain may be fed to livestock and poultry and the green plants provide a useful fodder. The straw, which is inferior to that of other cereals, may be fed to livestock, or used for bedding, thatching, fencing and fuel.

**Adaptation**

Bulrush millet is a short-day crop although there are some day-neutral cultivars. It is a warm-weather crop and is usually grown as a rain-fed crop in the semi-arid regions of the world. No other cereal grows as well in the hot dry regions as bulrush millet and it is therefore grown in areas that have prolonged dry periods, such as the Sahel-Sudan savannas of Africa. It is the number one crop in the Sahel savanna zone approaching the Sahara in tropical Africa; in the Sudan zone to the south it is of equal status with sorghum. Though it is less tolerant of drought as a seedling than sorghum, it is commonly grown on sandy, free-draining soils in areas where the early planting rains are unreliable. Though it is grown in drier areas than sorghum, unlike sorghum it does not possess the quality of remaining dormant during periods of drought and therefore requires a certain minimum amount of moisture for growth. It is sometimes sown before the rains and can so make use of the nitrogen flush which occurs when dry soils are wetted by the first rains. However, resowing is often necessary if the rains are delayed or irregular.

In the Sahel-Sudan savannas, short duration types of millet require about 220 mm of water, well distributed during July and August. The long duration cultivars may require up to 400–800 mm over a period of 3½ months. Cultivars with a medium growing period need 350–400 mm. Millet can endure drought periods of up to three weeks, but water stress in July always has a disastrous effect on yields, despite the drought resistance of the crop. Heavy rain during the flowering period interferes with fertilization and causes reduced yields.

Bulrush millet can be grown on a variety of soils, but light loams are preferred. It produces reasonably well on poor sandy soils on which most other crops would fail. It requires well-aerated soil and is not adapted to heavy soils. It cannot tolerate waterlogging.

**Botanical Description**

Bulrush millet is a freely tillering, tufted annual of up to 4 m tall, although some dwarf cultivars may be as short as 1 m. A single
CEREAL CROPS

A seminal root grows first, followed by adventitious roots which grow from the stem and tiller nodes below ground, and prop roots which arise from the lowest nodes above ground. The stem is solid and often much branched. It produces tillers which arise close to ground level. Branching occurs from any node and each branch and all the tillers may produce terminal panicles. The stem is narrow compared with sorghum, and it has prominent nodes marked by rings of long white silky hairs. The leaf sheath clasps the stem. The leaves are up to 1 m in length and up to 5 cm wide and are usually glabrous.

Fig. 34 Head of millet
They are smooth on the lower surface, but rough on the upper surface.

The inflorescence is a panicle with a stout, erect and finely hairy main axis (Fig. 34). It varies in length from 15–140 cm and is about 1–3 cm thick. The flowers are protogynous (stigmas exerted and receptive before anthers) and most of the stigmas are exposed to foreign pollen before the anthers appear on the spike; cross-pollination therefore amounts to about 75% or more. The spike is usually very dense as it has very many spikelets. Each spikelet contains two florets. The lower floret is usually male while the upper floret is perfect, having the stamens and an ovary with two styles fused at their base. Neither floret has lodicules. The grain is small and wedge-shaped, 3–4 mm long and easily separated from the enclosing lemma and palea. It varies in colour from white to dull-grey to blue with a black hilum.

**Cultivation**

*Cropping systems*

In the Sahel-Sudan savanna regions, millet is frequently grown for five or six years successively, followed by a prolonged period of bush fallow. On land that has reached a low level of fertility, three years of successive millet crops alternate with six years of fallow. Normally millet should be sown in rotation with groundnuts or any other legume crop.

Millet is generally intercropped with sorghum. In some regions, as in Chad, millet is intercropped with groundnuts. Two rows of groundnuts are sown between two rows of millet spaced 140 cm apart. In East Africa millet is also sown with groundnuts, cowpeas, pigeon peas and beans.

*Land preparation*

Like all other cereals, bulrush millet needs well-prepared land, but as it is the first crop of the season, most farmers sow it just after the first rain or sometimes even before rain without preparing the land. At the time of sowing the soil is so hard that only very rudimentary land preparation is possible. When it is intercropped with sorghum, land is prepared in the way described for sorghum. Where sowing is done on ridges, the ridges should be made well before sowing and the old ridges should be replaced by new ones.

*Sowing*

Clean, viable seed is necessary for good germination and a good stand. Most farmers usually sow the stored seeds left over from the previous year, and because of poor storage facilities, the viability of
these seeds cannot be guaranteed. To have a good and uniform stand of plants, the seed should be treated with chemicals before sowing. The two chemicals recommended for this are Aldrex T (aldrin and thiram) and Fernasan D (thiram). For about 3 kg of seed one packet of either of these chemicals is used. The instructions on the packet should be followed strictly. The container should be shaken thoroughly for about three minutes so that the seeds are completely covered with the chemical.

One of the main causes of poor yields of millet in Nigeria and other countries in West Africa is that many farmers rush to sow their millet with the first rain. More often than not there is a long interval before the next rainfall and in the interim period, many of the sown seeds have become dessicated owing to hot weather and inadequate land preparation. The few that do manage to germinate are stunted. By the time regular rain starts some farmers have lost half of their crop. The farmer is then faced with the decision of whether or not to resow. By the time he makes up his mind and decides to resow, he is already three weeks late from the actual establishment of rain. If, on the other hand, he decides not to resow, he would at best get half of the yield he would have obtained if he had been patient enough to sow at the right time. This ‘rush-sowing’ is a risk and merely waiting to sow at the right time will go a long way towards increasing the overall yield of millet.

Generally the best time to sow millet is when the rains are established. The result of a trial on date of planting conducted at Samaru (Nigeria) as reported by Egharevba (1979) is given in Table 10. While the last two weeks of May, depending on the onset of rains, is the most appropriate time for sowing in Samaru (11° 11’N and 7° 40’E), the middle of June is the most ideal sowing time in Kano.

<table>
<thead>
<tr>
<th>Planting date</th>
<th>Yield in kg/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Samaru</td>
</tr>
<tr>
<td>Mid-April</td>
<td>350</td>
</tr>
<tr>
<td>Early May</td>
<td>1072</td>
</tr>
<tr>
<td>Mid-May</td>
<td>2239</td>
</tr>
<tr>
<td>End of May</td>
<td>2460</td>
</tr>
<tr>
<td>Mid-June</td>
<td>1300</td>
</tr>
<tr>
<td>End of June</td>
<td>279</td>
</tr>
<tr>
<td>Mid-July</td>
<td>**</td>
</tr>
<tr>
<td>End of July</td>
<td>**</td>
</tr>
</tbody>
</table>

*Not planted because it was too dry  
**Grain yield not worth reporting
(12° 0' N and 8° 31'E). Regardless of the onset of rain, millet will not do well in Samaru and Kano if planted later than the middle of June and the middle of July respectively.

The recommended spacings are designed, together with other improved practices, to obtain maximum yields. However, the concept of maximum yields seems to be slightly different in terms of the goals of some farmers. With close spacing, although the yield is higher, the size of the head and grain are reduced. The size of the grain rather than the number of grains is an important factor to the farmer. The farmer thus retains the traditional spacing to obtain grain of the desired size. Furthermore, local millet cultivars tiller excessively which warrant spacing wider than that recommended. The recommended inter- and intra-row spacings are 90 cm and 30–45 cm, respectively. Where intercropping is practiced, the interrow spacing of millet is increased to 2 m.

The seed rate should be 3–4 kg/ha, but for the traditional system it is about 10 kg/ha because 5–10 millet seeds are planted per hill and then thinned to two plants three or four weeks after germination. Thinning should preferably be done after a good rain. Thinning to a population of two per hill is recommended. Millet compensates very readily for loss of stands or variations in spacings by increased tillering, and this is common with some local cultivars.

The correct depth of sowing is very important for the satisfactory establishment of the millet stand. Because of the short coleoptile and the small food reserve in the millet seed, it should not be sown very deep. Under no circumstances should seeds be sown more than 4 cm deep. The optimum depth of sowing in light, medium and heavy soil should be 3–4 cm, 2–3.5 cm and 1.5–2 cm, respectively.

**Fertilization**

Millet is seldom fertilized. The few farmers that bother to apply fertilizer do so at the wrong time and as a result no benefit is derived. Because of rudimentary land preparation and the uncertainty of rain, farmers generally do not apply any fertilizer at the time of sowing as they prefer to wait until the crop is established. Most farmers prefer to apply fertilizer first to the sorghum crop and then to the millet crop, because they are more sure of the sorghum crop. Because of this, the best time to apply fertilizer to millet is missed.

A millet crop yielding 2,000 kg grain and 7,400 kg stover per hectare, removes about 79 kg N, 36 kg P₂O₅ and 86 kg K₂O per hectare. Of this, 31 kg N, 15 kg P₂O₅ and 10 kg K₂O per hectare are removed by the grains and the rest is removed by the stover. As with sorghum, millet is very efficient in extracting nutrients from a large volume of soil and therefore some proportion of its nutrient requirements are met from the soil.
In a nitrogen/population trial, it was found that N application of up to 50 kg/ha and populations of up to 40,000–60,000 plants/ha significantly increased grain yields (IAR, 1976). In another trial, it was observed that the yield difference between single and split applications of N was not significant. However, a split application of 50 kg/ha, half at thinning and half at four weeks after thinning, produced the highest yield. In a variety/fertilizer trial at Samaru and Kano in Nigeria, mean grain yields showed no response to the increase in N application from 40–80 kg/ha (Balasubramanian and Mokwunye, 1978). This indicates that the amount of additional fertilizer beyond 40 kg N/ha contributes to an increase in vegetative parts and not grain. Thus a nitrogen dose of 40–50 kg/ha seems optimum for improved millet cultivars.

To obtain an optimum ratio between N, P and K, doses of 50 kg N, 25 kg P₂O₅, and 25 kg K₂O per hectare may be recommended for sole crops of millet under improved farming conditions. If the millet crop follows a groundnut crop, there is no need to apply nitrogen at all because the entire requirement of N can be met by the residual N left over by the legume. The incorporation of millet residues in the soil will also lessen the need for K fertilization. The method of applying fertilizers is the same as that used for sorghum.

**Weed control**

Farmers pay very little attention to weed control in millet especially when it is grown as a sole crop. In most millet-growing areas, one hand weeding and two hoe weedings should eliminate weed competition. Herbicides such as prometryne at 1.0 kg, a.i./ha or a mixture of atrazine and propazine at 0.5–0.5 kg a.i./ha as a pre-emergence application can give very reasonable weed control in millet. For these herbicides to be effective, they should be in the correct formulation, the land should be well prepared and the application of the herbicides should be timely.

**Harvesting and threshing**

The crop is harvested by cutting off the heads when the grain is fully ripe. In some heavy-tillering cultivars with uneven ripening, two or more harvests may be necessary. The ears are threshed by beating them with sticks or having cattle tread on them. The threshing percentage is about 55.

**Yields**

Yields of millet vary greatly in different parts of the world. Yields in Africa vary from 250–1,000 kg/ha. Yields of over 3,000 kg/ha have been recorded at research stations.
Storage
Millet grain stores very well and in this respect is superior to sorghum or maize. Millet which is to be kept for six months or longer should be treated with Gamma lin (lindane) dust to protect it from storage pests. The granary should be thoroughly cleaned before the grain is placed in it and then closed tightly.

Crop Protection

Diseases
In the past, millet diseases were not taken seriously in African countries but now the true magnitude of the losses caused by diseases has been fully appreciated. Downy mildew, smut and ergot are the major diseases, while the fusarium disease complex, grain moulds and leaf spot diseases are less important at present.

Downy mildew or green ear (*Sclerospora graminicola*) is the most serious disease of millet. Affected seedlings make poor growth and their leaves have brown streaks and a white bloom of sporangia on the under surface. The tillers showing secondary infection grow very little and form few or no heads. The heads are wholly or partially replaced by leafy shoots. Often the disease is noticed only by the green ear symptom. The primary infection is through soil-borne zoospores and high humidity helps in the spread of the disease. Early planted millets tend to escape the disease. Burning the infected plants and crop residues and following crop rotation every year would help to reduce the level of primary inoculum. The only long-term practical way to control downy mildew is through the development of resistant cultivars. Efforts are in progress throughout the world to find collections resistant to this disease.

Smut (*Tolyposporium penicillariae* Berf.) is especially serious in years when continued cloudy weather combined with high humidity prevails during the flowering period. The grains are converted into dark green shining smut spore (almost twice the size of normal grain) which later turn light brown and contain large quantities of smut spores. There is no effective method of control as the spores are carried by wind and infect the stigma. Very severely infected ears should be harvested and burnt. Seed treatment with thiram kills the spores sticking to the seed surface and reduces seed-borne infection.

Ergot (*Claviceps microcephala* (Woller.) Tul.): in Nigeria the primary infection occurs through sclerotia carried along with the grains to the next season, and the secondary infection is through conidia carried by insects, ants and raindrops. Small drops of pinkish or light honey-coloured sugary fluid called honey dew trickle down from the affected spikelets. The honey dew becomes
thicker and several dark sticky patches may be seen on the ear. The
duration of this stage depends on the weather conditions; if the
weather is wet this stage continues for a long time. The sugary
secretion contains numerous conidia which are carried by insects
from one spike to another. The spikelets are transformed into scler-
rotia and grain formation is inhibited. The spread of the disease can
be reduced by taking certain prophylactic measures. Only seed free
from sclerotia should be used for sowing and the ears showing
honey dew should be removed and destroyed to reduce the
inoculum.

Insect pests
The most common insect pest of millet in Nigeria is the stem-borer.
On the basis of recent surveys, however, the millet grain midge and
the head-worm are potentially major pests.

Stem-borers (*Acigena ignefusalis* Hamps): the larvae bore
directly into the stem without any leaf feeding. This can kill the
young plants or weaken and break the stems of older ones, and at
times, prevent grain formation. Sanitary measures such as the
destruction of infested stalks are the only effective measures of
control.

Millet midge (*Geromyia Penniseti* Felt): the millet midge closely
resembles the sorghum midge in most aspects. However, the work
of Coutin and Harris (1969) in Senegal showed that it is larger, the
eggs are laid on the florets and the larvae crawl into the spiklets, and
it is entirely nocturnal. Its effects are similar to those of the sorghum
midge and severe attacks could cause a total yield loss. Sowing
should be done early so that the main crop flowering is completed
before the adult midge population reaches damaging levels.

Other pests
Millet is also very susceptible to bird damage. This is the same as
described for sorghum above.
RICE
(Oryza sativa L.)

Rice is the most important food crop of about half of the human race. It is the leading cereal crop (and one of the oldest) of south and east Asia, which are thickly populated regions of the world. The beginning of its culture is seemingly lost in pre-history. The traditional use of rice in the Hindu religious ceremonies associated with birth, marriage and death, indicates its intimate association with the people of south and east Asia.

With the exception of cocoyam (Colocasia esculenta), rice is the only major food crop that can be grown in the standing waters of vast areas of flat, low-lying tropical soils. Rice is uniquely adapted for growth in submerged soils.

Origin and Distribution
The genus *Oryza* belongs to the tribe Oryzeae in the subfamily Poideae of the great family Gramineae. There are 25 species of *Oryza*. Of these only two species are cultivated, namely *Oryza sativa* L. and *O. glaberrima* Steud. *O. sativa* is the common rice grown throughout the warmer regions of the world whereas *O. glaberrima* is grown to a limited extent in the flood plains of West Africa. Indica and japonica are the main subspecies of the genus *sativa*

*O. glaberrima* probably originated around the swampy headwaters of the Niger river in West Africa. Its characteristics are smooth, hairless glumes, red grains, short legules with roundish tips, high seed dormancy and stiff upright panicles with few or no secondary branches. Its importance in Africa is decreasing as it is replaced by modern cultivars of *O. sativa*.

*Oryza sativa* has been cultivated in south and east Asia since ancient times. Zhukovsky (1962) considered that *O. sativa* was domesticated well over 5,000 years ago. The general consensus of opinion is that rice was domesticated in India, probably the coastal area of eastern India where there are marshy areas. The presence there of wild rice species, the cultivar diversity, including primitive coarse grain forms, and the presence of many dominant genes lend support to this view.

During very early periods, rice spread from India to southern China and to all the countries of south and east Asia. Rice spread from India to Iran, Syria, Egypt, Italy and Spain. The Portuguese introduced rice into Brazil and the Spaniards introduced it to Central America. *O. sativa* was also taken to West Africa in the early
nineteenth century. Rice has been grown in Africa since ancient times. Porteres (1956) traces back the cultivation of *Oryza glaberrima* in the central Nigerian delta to 1,500 BC.

**Area and Production**

Rice is grown in the tropical and subtropical regions of all the continents. It is grown even in the temperate regions of north China. During the 1960s and 1970s there was a constant increase in global rice production. During 1961–5 rice was grown on 124 million hectares in the world with an annual production of 253 million tonnes, whereas in 1979 the figures rose to 145 million hectares and 380 million tonnes, an increase of 16% in area and 50% in production. This increase in production was mainly due to the adoption of modern cultivars and improved cultural and management practices. In 1989, rice was grown on 146 million hectares and the total production was 506 million tonnes, a further increase in production of 33%.

Over 90% of the total rice crop is grown in south and east Asia. In hectarage, India, and in production, China, are the leading countries in the world. Africa accounts for 2% of total world rice production. In Africa there has been a rapid increase in rice consumption and also in production. There was a 47% increase in area and a 30% increase in producing from the average of the period 1961–5 to 1979, and a further 15% increase in area and 20% increase in production from 1979 to 1989 (Table 1). Important rice-producing countries (producing more than a million tonnes annually) in tropical Africa are Madagascar and Nigeria. In addition to these, Sierra Leone, Côte d'Ivoire, Guinea, Guinea Bissau, Liberia, Zaire, Tanzania, Mali and Senegal are the other main rice-producing countries of tropical Africa, producing more than 0.1 million tonnes annually.

**Utilization**

Rice is used mainly for human food and is consumed mostly in the form of whole grains. The processing of paddy or rough rice is designed so that a high yield of unbroken grain may be obtained. Paddy, on milling gives approximately 20% husks, 50% whole (unbroken) rice, 16% broken rice and 14% bran and meal.

Rice is usually cooked by boiling in water or by steaming, and is eaten with pulses, vegetables, fish and meat. It is also used in the form of parched rice, rice flakes, puffed rice and rice pudding. Starch made from broken rice is used as laundry starch and in the manufacture of cosmetics and textiles. Beer, wine and spirits are also made from rice. Rice wine, which may contain 10–15% alcohol, is usually made from glutinous rice.
Rice bran has a high oil content (14–17%). The oil is clear, light-coloured and odourless and can be used as a salad and cooking oil, for soap manufacture, as a carrier for insecticides and as an anti-corrosive and rust-resistant oil. Wax can also be obtained from the bran.

Rice hulls are used in many ways: as roughage for cattle feed, chicken litter, ammoniation for fertilizers, filter aid, burnt for floor sweepings and as filler for building materials. Rice hull ash can be used as a source of high-grade silica, in the manufacture of building blocks, as an absorbent, a soil conditioner, a carrier for pesticides and as filler for insulating materials.

Rice straw is fed to livestock. It is also used for the manufacture of strawboard, hats and mats, and for thatching.

Adaptation

Rice is grown under such widely differing conditions that it is difficult to define the climate that is most suitable for its development. One of the main reasons for this wide range of climatic conditions is the great diversity of rice cultivars. Except of course for Antarctica, every continent on the planet produces rice. It is grown from the equator to latitude 53° N (in China) and 40° S, and from sea level to 3,000 m in the Himalayas. The chief limiting factor to its growth is not climate but the water supply.

On account of its heat-loving characteristic, rice is a crop most suitable for the tropics and subtropics, although it is also grown during the summer in warm temperate regions. The great intensity of light and solar energy found in subtropical and warm temperate areas probably constitute an especially favourable factor in rice-growing and are perhaps responsible for high average yields. Lack of abundant sunshine because of cloudy weather is one of the causes of poor yields in tropical regions.

The mean optimum temperature for rice cultivation ranges between 20°C and 35°C. Indica cultivars require fairly uniform temperatures in the range of about 25–35°C. Japanica cultivars require average temperatures of at least 20°C for at least four months. Low temperatures during early growth do not favour tillering and early vegetative growth, and even in japonica cultivars, optimum temperatures for tillering are of the order of 30°C. However, lower temperatures on the whole are considered to have a favourable effect on the grain yields of japonica cultivars. Long periods of sunshine are essential for high yields.

Rice transpires 600–1,200 mm of water for each crop, and 1,000–1,800 mm is needed to produce a rice crop. Although lack of water is the primary constraint to high and stable rice yields, too much water is also a problem.
CEREAL CROPS

Sandy soils are usually unsuitable for growing rice. Their low capacity for holding water and nutrients and their high permeability make it difficult to maintain the necessary flooded conditions without using excessive quantities of water.

Rice grows under a wide range of soil acidity and alkalinity (pH 3.5–8.5). To a large extent its tolerance to variations in soil pH stems from the ability of rice to grow in submerged soil and the fact that under water the pH of acid soils increases and that of alkaline soils decreases by up to 2 units.

Botanical Description
Rice is an annual grass with erect culms 60–180 cm tall. It has a shallow root system which is mainly concentrated in the upper soil layer, to a depth of 20–25 cm. The young roots are white, thick, short and relatively unbranched. They elongate with age and produce a dense surface mat.

The culms are erect, cylindrical and smooth with solid nodes and hollow internodes. The number of internodes varies from 10–20, fewer in early cultivars of japonica and more in late-maturing cultivars. Buds in the axils of leaves at the lowest nodes grow out to produce tillers, which in turn can produce second- and third-order tillers. From each node there is one leaf. Each leaf has a lamina and long sheath which completely encircles the internode. The lamina is long (30–50 cm) and narrow (1.2–1.5 cm), usually hairy in O. sativa and glabrous in O. glaberrima.

The inflorescence is a loose and many-branched panicle. Each branch of the panicle bears one or more spikelets. The average panicle bears 100–150 kernels. The rice grain is enclosed by the lemma and palea, which together are called husks or hulls. On threshing, the husks and glumes are removed. The pericarp, aleurone layer and embryo, which are rich in protein and fat, are removed during milling and polishing, leaving mostly the starchy endosperm. The endosperm is usually white or translucent but other colours are also known. The size of the grain varies from 3.5–14.5 mm long, from 1.7–3.7 mm broad and from 1.3–2.3 mm thick. In certain cultivars the grain has a characteristic aroma.

High-yielding cultivars
Since 1960 much progress has been made in increasing the yield potential of the tropical rice plant. The traditional tropical rice plant, an indica type, is tall (usually 160–200 cm) with long drooping leaves. It has been bred and selected for dependable yields under low management levels, is tolerant to variations in water level in the field and competes reasonably well with weeds. It endures low soil
fertility conditions and is fairly resistant to insect and disease attack. However, the yield potential of traditional cultivars is low (about 2 tonnes/ha).

The main difference between the traditional and modern high-yielding varieties is that of plant type, sometimes referred to as plant architecture. The important characteristics of modern varieties are:

* short stature, the height ranging between 90 and 100 cm
* short, thick, sturdy stems imparting resistance to lodging at high nitrogen levels and in strong winds and heavy rains
* rather short and erect leaves of medium width, which allow the penetration of sunlight, improving photosynthetic efficiency
* high tillering capacity, which helps to produce more panicles per unit area of land
* a high grain to straw ratio, or harvest index. Usually the weight of grain and straw are about equal whereas in the traditional tall cultivars no more than one-third of the total dry matter is grain.
* photoperiod insensitivity. This means that the cultivar has about the same growth duration in the tropics regardless of the month in which it is planted.

Besides the above plant type characteristics, all the cultivars are very responsive to fertilization and good management practices. Many cultivars possess resistance to adverse conditions, such as insect and disease resistance, salinity resistance and drought tolerance.

**Cultivation**

**Cropping systems**
There are many cropping systems for rice cultivation. In the lowlands three systems are practised:

* monoculture, i.e. only rice is grown year after year
* a short-duration water-loving crop is grown before rice (the best example of this is the cultivation of jute (Chorchorus spp.) before rice)
* double cropping of rice.

In the uplands, rice is grown either as a sole crop or an intercrop, or in rotation with other crops which are either grown before or after the rice crop.

**Upland rice cultivation**
This is also known as dry-land rice cultivation or hill rice cultivation. Upland rice is grown as a rain-fed crop where there is adequate rainfall (at least 750 mm) for 3–4 months. Upland rice is much less
important in Asia as it covers only 10% of the total rice area, but it is very important in Africa where upland rice accounts for 75% of the total rice area. As irrigation facilities are becoming increasingly available, there is good scope for lowland rice cultivation in tropical Africa.

Upland rice is cultivated in a similar manner to other rain-fed, small-grained cereals and flooding is not needed. The water requirement of upland rice is almost half or even less than that of lowland rice. As a rule it is generally accepted that upland rice requires a rainfall of about 50–60 mm over each running 10-day period during 3–4 months of the growing season.

Upland rice is usually grown in hilly regions and also where shifting cultivation is practised. The land is not well prepared; in the traditional method of rice cultivation in West Africa, the land is normally incompletely cleared, often by burning, without uprooting the tree stumps, and the soil is lightly scraped with a hoe. The seeds are broadcast at a seed rate of 30–40 kg/ha. Other crops such as yams, cassava and maize are often interplanted or intersown with rice. Generally no fertilizer is used and weeding, if done at all, is carried out too late to be effective. The land is abandoned after 2–3 years of cultivation and is left fallow to revert to bush.

To obtain high yields the traditional techniques must be changed. Good ploughing up to a depth of 15–20 cm is essential to allow the plants to root sufficiently quickly and deeply to survive periods of drought that may occur in the beginning of their growth. The optimum seed rate is 50–70 kg/ha. The seed should be sown at a depth of 2 cm. Row seeding should be practised as it encourages a more uniform distribution of plants, and also allows early and efficient weeding. The inter-row space can be 30–40 cm, as with this spacing there has been no reduction in yield in comparison with closer row spacing. Adequate fertilizing is also essential: 80 kg N, 40 kg P₂O₅, and where potash is in short supply, about 40 kg K₂O per hectare will be required to obtain a high yield.

Upland rice has considerably greater weed problems than lowland rice, and weeding must be done early. A second cultivation is sometimes useful and may help to conserve water by reducing evaporation.

Lowland rice cultivation
This is also known as swamp rice, wet rice, or flooded rice cultivation.

The rice is grown on flooded or irrigated land. It is the most important cultivation system of rice in Asia and is now becoming popular in Africa. In this system the land is inundated and the crop
is grown in water from the time of planting until the approach of harvest. The depth of flood water does not exceed 50 cm.

There are two methods of lowland rice cultivation, the direct sowing method and the transplanted method.

Direct sowing: first of all bunds are constructed or repaired around the field to be cultivated. The method of cultivation is like that practiced under upland conditions. The soil is prepared in May-June after the first rain. The rice stubble should be ploughed under soon after the harvest of the crop and before the soil dries up. It is better to plough to a depth of about 10–15 cm. The soil is left bare and after the first rain the field is again ploughed. This destroys any weeds that have germinated. This is followed by harrowing or light ploughing only a few days before sowing, to break up the clods and level the field. The seed is broadcast at the seed rate of about 100 kg/ha or drilled in rows 30–40 cm apart, depending on the nature of the soil and the availability of a drill. Row-seeding both reduces the seed rate by half and enables weeding to be done with animal- or tractor-drawn implements, allowing easier control of weeds. Harrowing is carried out immediately after broadcast sowing. The crop grows under rain-fed conditions until the flood water arrives. Weeding should be done about 15 days after emergence. If necessary, a second weeding should be carried out before the plots are flooded. Sometimes the seeds are sown directly on a field after it has been flooded and puddled.

Transplanted rice cultivation: this method of rice cultivation consists of raising the seedlings by sowing seeds in well-prepared and raised nursery beds, and then transplanting the seedlings in a well-puddled and levelled field.

Land preparation
Land preparation for lowland rice cultivation starts with the bunding and levelling of the field to impound water and to permit even flooding. On hillsides the land is divided by contour bunds into fields. The bunds are made with controlled openings for letting the flood water in and out of the field. Ploughing of the land is as essential for lowland rice as it is for dry crops, although the end in view is somewhat different. For dry-land crops, soil tillage aims primarily at the improvement of the physical condition and a better water-air ratio in the soil. For lowland rice cultivation, the presence of oxygen in the soil is of less importance as the crop is adapted to waterlogged conditions. The chief objective of intensive soil tillage in lowland rice cultivation is to create the so-called puddled condition, which involves working up the soil to the consistency of a fine, soft mud by means of repeated ploughing, harrowing and
trampling (Fig. 35). The weeds and stubble are turned under the mud to decay. The whole of the upper layer of the soil should be in this smooth, soft, muddy condition, permitting the roots to ramify freely in the medium and allowing for flood water retention.

Williams (1975) has suggested that after flooding the soil should be maintained in the flooded condition to prevent the formation of nitrate which on subsequent flooding would undergo anaerobic denitrification to nitrogen gas. Estimates of the loss of nitrogen by this process are between 20 and 300 kg/ha.

The International Rice Research Institute (IRRI) in the Philippines has developed improved machinery adapted to small farms for all the phases of rice production, harvesting and processing. IRRI has developed a relatively inexpensive 5–7 hp tiller for soil tillage and puddling. It is now widely used in some countries and is expanding to new areas.

**Nursery raising**

For transplanting, seedlings are raised in either a dry or wet nursery. In the former the land is well-cultivated and fertilized with well-rotted farmyard manure. Nursery beds are made 1–1.5 m wide and of appropriate length. The beds are slightly raised. For planting one hectare of field, seedlings are raised in nurseries of about 350–500 sq m in area. Adequate fertilizer (60–100 g N and 50 g P₂O₅ per sq m) should be applied before sowing. Pre-soaked seeds are broadcast or
drilled in the prepared nurseries at the rate of 1–2 kg per 20–35 sq m. The seed is covered with 2–3 cm soil. Seedlings from a dry nursery are harder than those from a wet nursery.

A wet nursery is the more common method. The land is flooded and puddled and fertilized with farmyard manure and phosphate. Nursery beds are made as described above. They are also slightly raised. Pre-soaked, sometimes pre-germinated seeds are broadcast on mud at the rate of 25 kg per 350–500 sq m of nursery beds and water is allowed to stand continuously on the beds after the seedlings are about 15 cm high. Seedlings grow quickly and are ready for transplanting in 25–30 days, when they are 15–30 cm tall and have developed 5–7 leaves.

Sometimes the seeds are germinated on strips of polythene or other material which keeps the root system on the surface and easier to raise. Such seedlings are ready for transplanting in 10–14 days.

**Transplanting**

When the seedlings are ready, transplanting should be done promptly, although it is sometimes necessary to retain the seedlings in the nursery for much longer periods because of uncertainty about the time of the rains. In areas of deep flooding, very large seedlings, sometimes almost at the initiation stage, are used for transplanting.

The seedlings are pulled up in small bunches and transplanted soon afterwards. If the seedlings are tall the top portion of the leaves is sometimes pruned to reduce transpiration and to give rigidity when transplanting. During transplanting, a bunch of seedlings is held in the left hand and with the right hand 2–3 seedlings are thrust in the mud. Shallow planting is recommended, and care should be taken that at least one-third of the seedling remains above the water level. As far as possible, transplanting should be done in straight rows. The optimum row spacing (both ways) is 20–25 cm for long duration, and 15–20 cm for short duration cultivars. Transplanting is one of the hardest and most expensive operations in rice cultivation.

Besides these two systems described above, other systems, namely deep-water rice cultivation, mangrove rice cultivation and flood-water rice cultivation, are practised in certain localities on a very small scale.

**Fertilization**

The quantity of nutrients removed or taken up by a crop is a good index of fertilizer needs. Williams (1975) has reported that a high-yielding rice crop producing 4,074 kg of dry grain per hectare removed 90 kg nitrogen, 20 kg phosphorus, 219 kg potassium, 34 kg
calcium, 25 kg magnesium, 12 kg iron, 12 kg manganese and 1,780 kg silica. The most usual deficiencies in rice cultivation are nitrogen and phosphorus, with potassium and sulphur in limited areas, and silica on mostly peaty soils. The application of lime has a beneficial effect on acid soils. The use of nitrogen alone leads to depletion of the phosphorus reserve in the soil and a significant response to nitrogen is only obtained with the application of phosphate. P is more readily available in flooded soils and K is found in sufficient quantities in most rice-irrigation water. However, yield responses to the addition of these elements are common in the tropics. The use of heavy doses of N fertilizer also increases the requirement of these elements.

The impact of new high-yielding cultivars is most evident when substantial amounts of nitrogen fertilizer are applied to the rice crop. At high nitrogen levels, the modern cultivars tiller heavily, produce more grain per unit area of land and remain standing until harvest. They respond to as much as 120–140 kg N/ha. The old, tall cultivars, on the contrary, seldom respond to more than 30–40 kg N/ha, and on fertile soils may show no response whatsoever to applied nitrogen.

Urea and ammonium sulphate are equally satisfactory nitrogen fertilizers for rice. Because of denitrification losses, nitrogen should not be added in the nitrate form as a basal dressing. It may be used for supplemental dressings after the root systems are well developed and the nitrogen can be immediately absorbed. Sulphur-coated urea or urea blended with neem (Azadirachta indica) cake, lac or coal tar increases the efficiency of the urea resulting in higher yields (Yamade et al, 1976; Reddy and Prasad, 1977).

If nitrogen fertilizer is placed in the root zone rather than applied to the surface of the soil, losses from volatilization and denitrification can be greatly reduced. The increased efficiency makes it possible to obtain the same yield of rice from 60 kg/ha placed at a depth of 10–12 cm as from 100 kg/ha placed in the conventional manner (broadcasting). One method is to place the fertilizer inside balls of mud, which are then inserted into the soil between every four hills. Recently in the USA large granules and briquettes of urea have been produced to replace the mud balls and thus eliminate the tedious hand-balling process. About 60,000 briquettes are required for one hectare of land.

Phosphorus deficiency causes reduction in the number of tillers and a delayed and prolonged period of heading, with greatly depressed yields. In phosphate-deficient conditions hardly any benefit can be derived by adding nitrogen and potassium. Where phosphorus is required, it is usually applied at rates of 40–50 kg
P₂O₅ per hectare. The application of more than this generally fails to increase the yield. Flooding the field increases phosphate availability largely through the reduction of insoluble ferric phosphate to soluble ferrous phosphate (Ponnamparuma, 1955). In lowland rice soils, superphosphate appears to be a good source of phosphorus except on extremely acid soils. On these soils, rock phosphate and bonemeal are usually better than superphosphate. Phosphorus is usually applied as a basic dressing. In lowland rice soil, phosphorus is usually broadcast during the final land preparation. Katyal (1978) obtained higher yields of rice when P was broadcast than when it was mixed with the top 15 cm of soil, and with a single rather than with split applications.

Potassium availability is not a problem in most soils, but the addition of potassium is recommended in rice production to increase the resistance of the crop to certain diseases. Potassium can be applied in the form of potassium chloride or potassium sulphate. Research on the timing and method of application of K to the rice crop is reviewed by von Vexkull (1978). There is evidence that split applications or top-dressings produce better grain yields than basal applications of K.

**Weed control**

Yields of rice are seriously reduced by competition from weeds during the early growth stages. Weeds are a considerable problem in direct-seeded rice fields because there the weeds and rice germinate at the same time, and there is no standing water to inhibit weed growth. In transplanted rice, weeds are less of a problem as they are controlled during puddling. The standing water in the field during the growing season helps to eliminate many weed species. It has been found that to weed flooded, transplanted rice by hand may require only 300 man-hours of labour per hectare, whereas directly-seeded upland rice may require as much as 1200 man-hours per hectare. If weeds are not controlled in upland rice, the harvest is often reduced to zero.

To obtain good yields of rice, weeds must be controlled in time. They can be controlled by physical and chemical methods. If labour is available, two hand or hoe weedings at 2–3 weeks and 5–6 weeks after sowing or transplanting will be adequate. Labour is often a problem, however, as family labour is no longer available and hired labour has become scarce and expensive. Under these conditions chemical control is the only solution. In rice fields, weeds can be controlled with any of the following herbicides, all applied at the rate of 3 kg a.i./ha:
* Stam F-34 (propanil)
* Risane (propanil + fluorodifen)
* Tamariz (propanil + thiobencarb)
* Stam F-34 + Basagran (bentazon)

The herbicides should be applied 10–15 days after planting.

*Harvesting and threshing*

The right stage to harvest rice is when the ear is nearly ripe and the straw is still slightly green. This stage is reached in early and late maturing cultivars normally at 4 and 6 weeks after flowering, respectively. At this stage the moisture content of the grain is about 18–25%. The commonest method of harvesting is by hand, using a serrated sickle. Either the whole plant is harvested, or only the heads together with some of the straw are harvested. The harvested plants are left in the fields for 3–4 days to allow them to dry, and then they are brought to the threshing floor and stacked for drying before being threshed. In mechanized cultivation, harvesting is usually done by combine harvester.

Threshing is done either manually by beating the plants against a hard surface or on wooden planks, or by having animals tread on the sheaves. Threshing is also done by a foot-operated pedal thresher, or a portable drum-type thresher operated by an engine or by a small tractor engine. These threshing machines are economical and time-saving. After threshing, winnowing is done to separate the grains from the husks and chaff. The grains are then dried in the sun or in a dryer to 12.5–13.0% moisture content after which they are ready for hulling. With combines, harvesting, threshing, winnowing and bagging are done in one operation, after which the grains are dried in a dryer.

*Processing*

Riced may be parboiled before milling. This consists of steeping it in hot water, steaming it, and then drying it down to a suitable moisture content for milling. The commercial milling of rice comprises cleaning, hulling (removal of the hulls) and milling, a process in which the bran and the germ are partially or wholly removed. The whole kernels from which the hulls have been removed are known as brown rice. The bran of the brown rice grain is then removed by a machine. The product from this machine is unpolished milled rice from which the outer bran layers have been removed. The unpolished milled rice is then polished in a machine which removes the aleurone layer and any adhering particles, and yields polished rice (Fig. 36).
Yields
Few crops show such a high variation in yield as rice. The highest average yields are obtained in subtropical and temperate regions. The highest yields are obtained in Australia; more than 7 tonnes/ha. In tropical Africa, the average yields vary between 1 and 3 tonnes/ha.

Storage
Large losses occur during storage, chiefly the result of insect and rodent damage. Fungi and bacteria may reduce the quality if the relative humidity of the air in the storage space remains too high (above 70%) or if rainwater enters the storage building.

Fortunately these losses can be virtually eliminated. The cardinal rules for good storage are to allow only clean and properly dried rice (milled or unmilled) to enter storage and to keep the storage building completely rain and rodent proof. In addition, the floor should be watertight so that no moisture seeps upwards through it.

Fumigation is the only practical way to control insect damage. The jute bags used for storage should also be treated with chemicals or fumigated.

Crop Protection

Diseases
Blast (*Pyricularia oryzae*) is one of the most common and serious diseases of rice. It can attack the plant at all stages. If the plants are
attacked in the early stages, the grains do not fill. High relative humidity (more than 90%) and high nitrogen application favour its spread. It is a seed- and air-borne disease. The application of silica and potassium helps to control the disease. Adjustments in cultural practices, such as time of planting, spacing and depth of transplanting, reduce the incidence to some extent. Row and Padmanabhan (1976) reported that a foliar spray of Hinosan (edifenphos) or kasumin was effective against the disease.

**Stem rot** (*Helminthosporium sigmoideum*) is widespread, particularly in south-east Asia, where it is almost endemic. It persists throughout the growing season and causes reduced yields under poor conditions of husbandry. The use of resistant, non-lodging cultivars is perhaps the only satisfactory basic approach to controlling the disease. The proper use of fertilizers helps to reduce the damage; excess nitrogen tends to increase the incidence of the disease, and potassium tends to reduce the damage.

**Narrow brown spot** (*Cercospora oryzae*) is a world-wide disease. It spreads rapidly if good screening for diseased seedlings is not practised. Resistant cultivars, where available, should be grown and hygienic measures should be adopted.

**Bacterial leaf blight** (*Xanthomonas oryzae*) is a widespread disease. In the seedling and crop stage the leaves are affected, but in severe form the grains may also be infected. No single effective measure is available for the control of the disease, and integrated measures, including the avoidance of flooding or deep water in the nursery and spraying with chemicals in both nursery and field, are suggested. Krishnappa and Singh (1977) have reported that 5 foliar sprays of 250 p.p.m. Agrimycin 500 a.i. at 12 day intervals, beginning 23 days after transplanting, were most effective against the infection.

**Virus diseases:** a number of virus diseases such as tungro, yellowing dwarf, grassy stunt, orange leaf and mosaic also occur in rice, being transmitted by leaf-hoppers. Resistant cultivars should be grown where available. Roguing out diseased plants and controlling the leaf-hoppers keeps the diseases in control.

In addition to these, the rice crop can be damaged by several other diseases caused by nematodes and physiological disorders.

**Insect pests**

Insect pests cause extensive damage to the crop from the seedling stage to the ripening stage, and also to grains during storage. The worst insect pests are the various species of stem-borers, plant bugs, worms and grasshoppers. The major pests are described overleaf.
Stem-borers are the most damaging insect pest of rice. The species which attack the rice crop are:

* yellow stem-borer – *Tryporyza incertulas* (Wlk.)
* rice stem-borer – *Chilo suppressalis* (Wlk.)
* purple stem-borer – *Sesamia inferens* (Wlk.)
* striped borer – *Chilo polychrysa* (Meyr.)
* white stem-borer – *Tryporyza innatala* (Wlk.)
* American sugar-cane borer – *Diatraea saccharalis* (F.)
* American rice stalk-borer – *Diatraea plejadellus* Zinek.

The eggs are laid on the leaves. The larvae, after feeding on the leaf surface for a few days, tunnel into the stem, often killing the main shoot and producing a dead heart or damaging the inflorescence to give the condition of premature white heads. The larva pupates in the stem and finally emerges as an adult moth. Several generations are produced in one crop and where two or three crops of rice are grown in succession, a big population build-up can occur.

Deep ploughing followed by submergence assists in control. Some cultivars show a certain amount of resistance. The use of systemic insecticides in granular form, if applied in the irrigation water, is helpful in controlling the insects.

Plant bugs: the most serious species are the rice-gundhi bug (*Leptocorisa varicornis*) and the paddy bug (*L. acuta*). They cause considerable damage by sucking the vegetative parts and grain at the milk stage. Awned cultivars are the least prone to attack. Dusting with 5% Bi1C (lindane) controls the insects.

Worms can also be a problem. The species which attack rice are:

* armyworms (*Mythimna separata* Wlk. and *M. unipunctata*)
* swarming caterpillars (*Spodoptera Mauritia* and *S. frugiperda*)
* case worms (*Nymphula depunctalis*).

They damage the leaves, sometimes so severely that only the leaf veins are left. The use of kerosene oil in the water and the use of BHC have been found to be effective in controlling these insects.

Grasshoppers also attack the rice crop. The most serious species are:

* green leafhoppers (*Nephotettix apicalis* and *N. impicticeps*)
* brown planthoppers (*Nilaparvata lugens*).

These insects cause much damage by the loss of sap from grains, the injection of toxic salivary secretions, and the transmission of several viruses. They can be controlled with suitable insecticides. Some cultivars are resistant to these insects.
CEREAL CROPS

WHEAT
(Triticum aestivum L.)

From the earliest times, wheat has played an important role in the development of civilization. The cultivation of wheat reaches far back into history, and the crop was predominant in antiquity as a source of human food. Wheat is one of the important cereals of the world. It is the number one cereal of the temperate regions of the world, which are climatically very suitable for its cultivation. Nowadays it is also grown on a large scale in the subtropical and tropical regions of the world.

Origin and Distribution
Different species of wheat have originated in various localities in the area adjoining southern Turkey, Iraq and the adjacent territories of Syria, Iran, and Transcaucasia (USSR). Helback (1966) reported that grains of domesticated wheat were found in the archaeological remains in Ali Kosh in Iranian Khuzistan, dating 6,500 BC, and in Anatolia in Turkey, dating 5,500 BC.

The cultivation of wheat spread from its centre of origin to India, Pakistan and China in the east, to the Mediterranean countries in the west, and to the USSR and other European countries in the north. Some 5,000 years ago wheat was taken to Ethiopia by the early immigrants. The greatest diversity of Triticum durum L. (a wheat species) is found in Ethiopia. In the very recent past the crop was introduced to the Americas and Australia. Today, wheat is grown in most temperate and subtropical countries, and in many tropical countries.

Area and Production
The area and production of wheat in the world during 1961–5, 1979 and 1989 are given in Table 1. The areas for 1961–5 and 1979 were 210 and 239 million hectares, showing an increase of 13.8%, while production increased from 254 to 455 million tonnes, showing an increase of 79%. This remarkable increase in production was due to the increased use of fertilizer and high yielding cultivars, and improved husbandry. There was a slight decrease in area (5%) but a further increase in production (19%) from 1979 to 1989. For wheat production, the important countries are the USSR, China, the USA, India, Canada, France, Turkey, Australia, and Pakistan.

As a continent, Africa is not important for wheat production. Africa produces only 2.46% of the total world production (Table 1). In 1989, Africa produced 13.22 million tonnes on 8.61 million hectares. The share of tropical Africa is very low: only four countries
(Zimbabwe, Ethiopia, Sudan and Kenya) produced more than 0.1 million tonnes.

Utilization
The whole grain of wheat contains approximately 70% carbohydrate, 11.5% protein (varying from 8–15%), 2% fat, 2% fibre, 1.5% ash and 13% water. In milling wheat for flour, the pericarp and germ, which are rich in protein, are removed from the grain and the resulting flour is less nutritional than the whole grain.

Unlike many other cereal crops, wheat is mainly a food rather than a feed crop. After processing, the crop product is consumed directly by man, usually as a flour product. The flour is used for such products as bread, pastries, cakes, crackers, macaroni and spaghetti. A small amount of wheat is also used in the manufacture of dextrose, alcohol and certain breakfast foods.

In producing white flour, the germ is removed and as much as 30% of the weight of the grain goes to by-products such as bran, middling and shorts. All of these by-products are higher in protein content than wheat flour itself and serve as a valuable protein supplement in livestock feeds.

Variations in the milling process yield different types of flour. The inclusion of bran materials and germ in the final product yields wholewheat flours that are usually brown. These flours do not satisfy the taste of many consumers but they have a higher nutritional value than white flour.

The straw provides a valuable fodder. It is also used for making baskets and hats, thatching and as packing material.

Adaptation
Wheat is grown from the tropics to 60°N and 40°S. Though wheat is a temperate region cereal, it is grown in the tropical and subtropical regions of the world. In the tropics, wheat is grown at higher altitudes where suitable conditions exist in the lowlands. In the tropics and subtropics, it is grown only during the winter season. In East Africa, most of the wheat is grown at altitudes between 1,600 and 3,000 m. In the northern regions of West Africa it is grown during the dry (winter) season with irrigation.

Wheat can be grown successfully under a wide range of rainfall and temperature conditions. It can withstand the cold of the northern areas quite well; it grows successfully in hot climates if the humidity is not too high. It is not well adapted to areas where warm, humid conditions prevail, largely because such conditions favour the rapid development of diseases.

Because most wheat is produced on dry land, the availability of
moisture is a major factor in wheat production. Both the amount and distribution of precipitation are of prime concern to wheat producers. Where wheat is grown with irrigation, the distribution of natural precipitation is not critical. Wheat requires 250–750 mm of annual precipitation.

The ideal temperature for different stages of the wheat plant varies considerably. For instance, the optimum mean daily temperature for germination ranges from 20–25°C, while the optimum temperature for good tillering is much lower (16–20°C) and for the proper development of the wheat plant the best temperature range is 20–23°C. At mean daily temperatures higher than 20°C in the early tillering phase, tillering is poor and heading is accelerated. At temperatures higher than 25°C in the grain development phase, the plant dries up prematurely.

Wheat can be grown successfully under a wide range of soil conditions, but it is best adapted to fertile, well-drained silt and clay loam soils. Although it often produces satisfactory yields on clay soils and sandy loams, it is poorly suited to these and poorly-drained soils.

**Botanical Description**

The temperate cereals (i.e. wheat, barley, rye and oats) all have the morphological and anatomical features which characterize the family Graminaeae. Their leaves have no petioles but consist of a lower clasping sheath section and an upper expanded blade which is long and narrow with parallel veins. They are arranged alternately at the nodes. No tap root is formed, but 3–6 seminal roots from the seed are followed by a fibrous root system which develops adventitiously from the basal nodes of the stem and its main branches.

The cereals also have in common a tufted or tussocky habit of growth, a feature which is found in all annual grasses. Primary lateral branches (or tillers) arise from buds in the axils of the basal leaves of the main stem, and secondary laterals arise from the basal nodes of the primary ones. Each plant normally produces 2–3 tillers under typical crowded field conditions, but individual plants on fertile soils with ample space may produce as many as 30–100 tillers. The internodes of the main stem and its tillers do not elongate during the vegetative phase of growth, resulting in a crowding of the branches and leaves into the ‘tufted’ crown form. The elongation of internodes occurs with the initiation of the terminal inflorescence primordia. The young inflorescences are carried upwards by the developing stems or culms and finally emerge from within the encircling sheath of the last leaf as the head or panicles of flowers.

The flowers or florets are small. They consist of a bract-like
Fig. 37  Spikes of common wheat: (A) beardless; (B) bearded (awned)

lemma and palea which enclose three stamens and a unilocular gynaecium which has one ovule and a bifid style with feathery stigmas. The awn (Fig. 37) arises dorsally on the tip of the lemma in awned types. The florets are also arranged in characteristic clusters known as spikelets.

The cereal grain is a one-seeded fruit with a dry indehiscent pericarp known as the caryopsis. In wheat it is ovoid to broadly ellipsoidal with a deep crease on the side which faces the palea. It has an embryo about one-third or less its length on the opposite, convex or lemma side at its base, and a tuft of hairs or "brush" at the apex. The caryopsis consists of the pericarp, seed-coat, aleurone layer, starchy endosperm, and embryo (germ). In wheat, the starchy endosperm constitutes about 82–86% of the dry weight of the grain. The average spike (head) of common wheat contains 25–30 grains in 14–17 spikelets. Large spikes may contain 50–75 grains.
Species and cultivars

There are many known wild and cultivated species in the genus *Triticum* and there are thousands of cultivars. The principal wheats of commerce are varieties of the species *T. aestivum*, *T. durum* and *T. compactum*.

A wide range of cultivars has been bred in temperate, sub-tropical, and (at higher altitudes) tropical regions to produce locally adapted cultivars. One of the greatest developments in modern times has been the production of dwarf cultivars suited to the warmer countries. These cultivars are very responsive to high doses of fertilizer and high levels of management. They are high-yielding cultivars and have revolutionized agriculture in many countries.

Cultivation

Cropping systems

With the advent of photo-insensitive cultivars, the old concept of crop rotation has changed completely. Under new wheat-based farming systems no farmer is willing to keep his land under fallow or green manure crop before sowing wheat. With assured irrigation and good management, wheat can be grown in rotation, with one or two crops per year. Jute-rice-wheat, green gram-rice-wheat, sugarcane-wheat, potato-wheat, maize-potato-wheat and several other unusual crop combinations have started becoming common in different parts of the world. Where there are irrigation facilities, some of these and other combinations can be practised in suitable wheat-growing areas in tropical Africa. In Nigeria, wheat cultivation is becoming very popular. There wheat is grown during the dry season (November-April) with irrigation. With good management, a second crop, either maize, sorghum or millet, can be grown during the wet season. The same could be practised in different countries of tropical Africa where winters are mild and irrigation water is assured.

Land preparation

Recent studies have clearly shown that when adequate attention is given to the control of perennial weeds, more than two ploughings are wasteful. After a pre-sowing irrigation, a single harrowing is sufficient to create a satisfactory seed bed.

Sowing

The optimum time for sowing is decided by several factors, the most important of which is the temperature during the growing season. However, the ideal temperature for different stages of the wheat plant varies considerably (as already discussed under the heading
Adaptation. The effective wheat-growing season may vary in different countries and even in different regions of a country. In Nigeria, the middle to end of November has been found to be the most suitable time for sowing.

For high-yielding, short-stature cultivars, a seed rate of 100–125 kg/ha has been found desirable. Where, due to climate, early growth is restricted or the growing season is short, a higher seed rate (more than 125 kg/ha) is recommended. Today drill-sowing is practised almost all over the world. For a good crop of wheat yielding 5 tonnes/ha there should be about 500 earheads per square metre. Such a stand can be achieved at a seed rate of 100 kg/ha with rows spaced at 22.5 cm for all those cultivars which tiller readily, and at a seed rate of 125 kg/ha with rows spaced at 20.0 cm for the cultivars which are shy in tillering.

The high-yielding dwarf wheats are not only dwarf above ground, they are equally dwarf below. They have shorter coleoptiles than the old, tall cultivars. It has been reported that sowing up to 5–6 cm deep does not have any adverse effect on the emergence percentage. Sowing beyond this depth, however, results in a marked reduction in emergence percentage.

Fertilization

With modern high-yielding cultivars there is almost always a response to fertilizers. Unlike the tall cultivars which lodge severely at nitrogen rates higher than 40 kg/ha, the dwarf wheats have shown commendable response to nitrogen up to 120 kg/ha. Some cultivars may respond to a higher level of nitrogen but that may not be an economic response. Irrespective of the type of soil and agroclimatic situation, a dose of 100–120 kg/ha can be safely recommended.

In medium- to heavy-textured soils, the application of nitrogen either all at sowing, or in two splits (half at sowing and half at crown root initiation, i.e. 20–25 days after sowing), or in three splits (one-third at sowing, one-third at crown root initiation and one-third about three weeks after the second application) has given similar results. On very light soils, applying the total quantity of nitrogen at sowing is not as efficient as split application in two or three doses. Broadcasting nitrogen, if done uniformly, is as good as placement by drill.

In general, wheat responds well to the application of phosphate, except on soils of medium- to high-available P status. Even on such rich soils, a low dose of P₂O₅ (say 20 kg/ha) may give a sizeable response. However, for high-yielding cultivars on soils where the P status is not very high, a dose of 40 kg/ha can safely be applied.

Unlike nitrogen, drill placement of phosphate is desirable to
obtain a good response from phosphatic fertilizers. It is best to apply P at or before sowing.

Potassium or any trace elements should be applied only where there is a deficiency of these elements. Where there is a deficiency of K, it should be applied at the rate of 40 kg/ha. Under intensive cultivation with modern wheat cultivars, a Zn deficiency may be observed, and this element should be applied in the form of zinc-sulphate at the rate of 25 kg/ha. Both K and Zn should be applied before the last cultivation.

**Water use**

In modern high-yielding cultivars, the crown root initiation stage has been found to be the most critical stage as far as water use is concerned. This is the stage when the first irrigation is to be applied. In a timely sown wheat crop, this stage is reached about three weeks after sowing. Crown roots generally develop within 2 cm from the surface soil. If there is sufficient moisture at this depth at the crown root initiation stage, crown roots will develop normally and there will be no need for irrigation at this stage, but in most places the top 5–10 cm of the soil is usually dry by the time crown roots start initiating. A delay in the development of crown roots also results in a corresponding delay in the development of tillers and ultimately lower grain yields. The irrigation scheduling for wheat has been discussed in Chapter 6.

**Weed control**

If wheat is grown with the cultivation practices as described above, weeds will not cause much loss. The thick sowing of wheat in narrow row spacing does not permit mechanical weeding. Under intensive farming, where the time factor is very important, the use of chemicals is the only suitable method of controlling weeds.

The non-graminaceous annual weeds such as *Chenopodium album*, *Carthamus oxyca//tha*, *Asphodelus tenifolius*, *Melilotus* spp, and others can be effectively controlled by a spray of 2,4-D (better amine-formulation) at 1.0 kg a.i./ha in 750 l of water five weeks after sowing. To control grass weeds such as *Phalaris minor*, *Avena fatua* and a few others, is a little more difficult. Bhundivali (1978) has reported that the pre-sowing application of Avadex (diallate) at 1.0 kg a.i./ha mixed in the top 2–3 cm of soil gives selective control of *A. fatua*. However, fine seed bed preparation and incorporation at the specified depth are very important for the effectiveness of this herbicide and if they are not strictly adhered to, the germination of the wheat crop may be affected or satisfactory weed control may not be achieved. Likewise, the pre-emergence
application of Tok E-25 (nitrofen) at 1.5 kg a.i./ha has given satisfactory control of P. minor. Satisfactory control of these two grass weeds can also be achieved with the application of Tribunil (methabenzthiazuron) applied at the rate of 1.5 kg a.i./ha either pre-emergence or about 30 days after sowing.

Harvesting and threshing
Wheat is harvested somewhere in the world every month of the year. The wheat crop usually ripens about 30 days after the 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 their green colour and become golden yellow. From this stage onwards, ripening consists of the gradual loss of moisture of the kernels. When completely air-dry, the moisture of the kernels averages about 10–12% . At this moisture level, the grains can be stored safely. When bird or storm damage threatens, or where there is a likelihood of early summer rain, the crop may be cut and bound into sheaves as soon as it is yellow, and stacked in the field or under shelter for complete drying.
Harvesting may be done by hand with sickles, or by machine. Where the harvest period is dry, the harvesting and threshing of the standing crop by combine harvester is practical. For combine harvesting, the grains must either be thoroughly dry or there should be arrangements for drying. On a small scale, threshing is done by thresher or by having bullocks tread the harvested materials. Where harvesting and threshing are done manually, winnowing must be done to separate the grain from the chaff.

Yields
There is great variation in the average yield of wheat in different parts of the world. Yields are normally higher in temperate regions than in subtropical and tropical regions. The average yield of wheat in the world is about 2,300 kg/ha whereas it is about 1,500 kg/ha in Africa. The highest average yield is about 6,300 kg/ha in France. In Nigeria yields of up to 2,500 kg/ha have been obtained. This shows that there is a possibility for increasing the yields of wheat in tropical African countries.

Storage
Drying to 10% moisture content and thorough cleaning of the grains are the first requirements for safe storage of wheat in the tropics. Protection from storage insect pests is particularly important. For this, storage structures and grain containers, including the bags,
should be well treated with insecticides. Fumigation of the grain soon after storing is equally important.

Crop Protection

Diseases

Rusts attack a wide range of cereals and grasses, but the forms are specific and there is no cross-infection:

* **black rust** (*Puccinia graminis*) attacks all the temperate cereals and grasses. The possibility of raising wheats which are resistant to the attack of black rust has been patiently investigated for many years. *T. durum* and *T. dicocum* are generally more resistant than *T. aestivum*.

* **yellow rust** (*Puccinia striiformis*) is the most common wheat rust. It can readily be distinguished from other cereal rusts by the deep cadmium yellow colour of the postules which are closely crowded together in parallel lines. Weather and soil conditions play an important part in determining the intensity of yellow rust attack. Cool, moist weather favours its development. It is most severe on fertile land, and when adequate nitrogen has been applied. The only way to avoid losses through yellow rust is to grow cultivars which are not markedly susceptible to its attack.

Smuts can cause considerable losses in wheat. There are two types of smut disease:

* **covered smut** of wheat (*Tilletia caries*), also known as ‘bunt’ or ‘stinking smut’, cannot be detected until the affected plants come into flower. The young ears are then of a slightly darker green colour than those of healthy plants. At this stage the grains are deep green in colour and, when crushed, are found to be filled with a black greasy mass of spores with an unmistakable fishy smell. Covered smut of wheat can be prevented by treating the seed before sowing with a suitable seed disinfectant such as dusts or liquid formulations of proprietary organo-mercury seed dressings.

* **loose smut** of wheat (*Ustilago nuda*) cannot be detected until the plants are in full flower. By the time the grains have started to swell all that remains of the ears of infected plants is a blackened stalk. As the fungus is not on the surface of the grain but inside it, seed treatment with organo-mercury will not prevent loose smut. One method of control is the warm-water treatment. The seeds are first immersed in cold water for about four hours. They are then taken out, drained for a few minutes, and submerged for ten minutes in a tank of warm water. The temperature of the warm water must be kept between 52 and 54°C.
Insect pests
The main insect pests of wheat are wheat stem sawflies, hessian flies, apids and cutworms.

Wheat stem sawflies cause significant losses by seriously damaging the stems of wheat plants. The insect lays its eggs inside the stem, causing it to split. The damage caused by sawflies ultimately results in lodging. Control of this pest is best achieved by growing cultivars with solid stems in which larvae cannot feed, and by rotating crops, which deprives the pest of a suitable host.

Hessian flies are a periodic pest of wheat. The larvae feed in individual tillers, causing lodging or death. Control of this fly is achieved through regulating sowing dates; delayed sowing is to be preferred.

Aphids can be a pest in wheat either by feeding on and damaging the crop directly, or by transmitting viral diseases. Phosphorus insecticides provide some effective control.

Cutworms are a serious pest in wheat. The caterpillars start damaging the crop from the instant they emerge from the egg. They remain hidden in the soil during the daytime and come out in the evening to cut the plants and feed on them. Soil treatment with 5% aldrin at 25 kg/ha at the time of preparing the land has been found to be very effective.
BARLEY
(Hordeum vulgare L.)

Barley is a major source of food today for large numbers of people living in the cooler, semi-arid areas of the world where wheat and other cereals are less well adapted. In many countries of the Middle East and northern Africa, barley constitutes the major part of total cereal production. Barley is the most important grain used in the brewing of beer.

Origin and Distribution
Cultivated barley (Hordeum vulgare) probably evolved from a wild ancestor (H. spontaneum Koch.) in the Near East. According to Helback (1966), barley, together with emmer wheat, was the first cereal to be domesticated in the Middle East at least 6,000 years ago, and was probably the most important of the early cereals. The wild species H. spontaneum Koch. is naturally distributed around the Syrian plains and the Euphrates river basin as a weed. The movement of barley from its centre of origin to different parts of the world is almost the same as that of wheat (discussed above).

Area and Production
In the world, barley is the fourth cereal after wheat, maize and rice. The total area sown and production of barley in the world in 1989 were 72 million hectares and 169 million tonnes, respectively. The area and production in Africa for the same year were 5 million hectares and 5.7 million tonnes, respectively. The world’s largest barley producers are the USSR, Germany, China and the USA. It is also grown in India, Iran, Turkey and Korea. Africa shares only 3.4% of the total world production. In tropical Africa, Ethiopia is the only country where barley is a major crop. Its cultivation has just been started in northern Nigeria.

Utilization
Barley grains (not malting barley) contain approximately 68% carbohydrate, 12% protein, 2% fat, 3.5% fibre, 1.5% ash and 13% water. Barley is used as human food, livestock feed, and for malting purposes. The most important use of barley is for malting. As a food it is consumed on a very small scale, mainly in Asia. Malt is used in making alcoholic beverages, mainly beer and whiskey. Barley is considered to be the best of the small grains for malting purposes.

For malting, both two-row and six-row hulled types are suitable. The former is generally used in Europe and the latter in North America. A low nitrogen content is required in malting barley. The
manufacture of beer from barley comprises two major processes: malting and brewing.

Malting is a controlled germination process which produces a complement of enzymes which are able to convert cereal starch to fermentable sugars, to secure and adequate supply of amino acids and other nutrients for yeast, and to modify the quality of the macromolecules which have such important effects on the physical quality of beer.

Brewing is the process of converting the starch to an alcohol, first by transforming starch to sugar and then by fermenting the sugar to alcohol by means of yeast. About 75% of the starch in malting barley is generally fermented to alcohol.

Barley is a highly satisfactory livestock feed. It is about equal to maize in feeding value for dairy cattle, and it has about 95% of the feeding value of maize when fed to pigs. It is an excellent feed for poultry and can be satisfactorily used in both mash and scratch mixtures.

**Adaptation**

Barley is grown in many different climates, from 70°N in Europe to arid regions near the Sahara and the high plateau of Tibet. It is grown throughout the more temperate regions of the world. It thrives well in a cool climate, and withstands more heat under semi-arid than under humid conditions.

The optimum temperatures for germination and emergence are 15–20°C. Although germination may take place even at 2°C, emergence is very slow at such low temperatures. Although young barley plants have considerable tolerance to cold, the temperature at which vegetative growth proceeds normally is around 16–17°C. Temperatures as high as 40°C during ripening are reported to have caused less damage to barley than to wheat (Arnon, 1972). As barley matures earlier (90–120 days) than wheat, it may escape excessively high temperatures during grain formation.

Barley is more drought-resistant than wheat and can be grown in a region of even minimum rainfall (200–250 mm). Although barley is more resistant than wheat, excessively hot or dry weather after heading will prevent normal maturation and produce grains which are lighter but high in nitrogen content, and which have reduced value for malting. The production of barley with good malting quality is therefore generally associated with regions of high rainfall and humid weather conditions, while most barley grown in the dry regions is produced mainly for feed.

The soils suitable for wheat are also suitable for barley, i.e. well-drained loams and clay loams. Barley is generally grown on less
fertile soils, the best ones being reserved for wheat. Barley is the most salt-resistant of the small grain cereals, both during germination and later stages of growth. It is grown on soils with a pH higher than 6.0. Barley is very susceptible to waterlogging.

**Botanical Description**

Barley belongs to the grass tribe Hordeae, in which the spikes have a zigzag rachis. It belongs to the genus *Hordeum*. Plants of *H. vulgare* attain a height of 0.5–1.0 m and tiller freely. The lateral spread of the barley roots usually varies from 15–30 cm, while the depth of penetration varies from 90–180 cm. The leaf blade is linear-lanceolate, 22–30 cm long and 1.0–1.5 cm broad, with a pronounced ligule.

The inflorescence is a spike with three spikelets borne at each rachis node. The spikes are 7.5–10.0 cm long and usually contain 10–30 nodes. In six-row barley, all three florets at a node are fertile, while in two-row barley, only the central floret is fertile. Each spikelet is subtended by a pair of glumes with short bristle-like awns. A floret consists of two lodicules, three stamens and an ovary with two feathery stigmas. The fertile floret is also composed of a lemma and a palea, and a caryopsis when fertile. Except in hull-less cultivars, the lemma and palea adhere to the caryopsis when mature. The lemma may terminate in an awn or hood, or it may be merely rounded or pointed. The grains are about 8–12 mm long, 3–4 mm wide, 2–3 mm thick and tapering at both ends. About 12–13% of the kernel consists of hull, except in the naked (hull-less) cultivars which are free from the hull after threshing.

**Types of barley**

The cultivated barleys are classified into two species, on the basis of the fertility of the lateral spikelets, viz. six-row barley (*Hordeum vulgare* Lam.) and two-row barley (*H. distichum* Lam.).

Six-row types appear to have a whorl of six florets at each rachis node, but there are in fact only three spikelets at each node, each having only a single floret. The floret in each of the three spikelets at each rachis node is fertile and thus three kernels are formed at each node. In two-row types, the lateral spikelets bear a sterile floret so that the mature spike appears to have only two rows of kernels (Fig 38). According to another classification, there are two groups: hulled and hull-less or naked.

Barley grown in Europe and Australia is mostly of the hulled two-row type, and in the United States and western Europe, six-row type hulled barley is grown. The six-row type is also predominant in India and the Middle East. Hull-less or naked types of barley are cultivated extensively in south-east Asia. The yield of grain is lower
than that of the hulled types, and the spikelets have a tendency to shed grain when ripe, thus further reducing the yield. Hull-less types have weaker straw and are more liable to lodge than the hulled types. The absence of hull makes them unsuitable for malting, but they are useful as food, having a higher digestibility (94%) than the hulled types (83%).

The hull of barley (in hulled types) protects the grain from predators and serves a useful purpose in the malting and brewing processes. It amounts to 13% of the grain (by weight) on average. Winter barleys have more hull than spring types; six-row (12.5%) more than two-row (10.4%); and the proportion of hull increases as the latitudude approaches the equator, e.g. 7–8% in Sweden, 8–9% in France, 13–14% in Tunisia. Large and heavy grains have less hull than small light-weight grains.

Cultivation

Cropping systems
Barley does well when grown in rotation with maize or any leguminous crop. Where barley can be grown in tropical Africa, maize, sorghum, groundnuts, cowpeas or beans can be grown as a preceding crop. Under rain-fed conditions, barley is grown with some other crops, such as gram (Cicer arietinum). In temperate
countries where it is grown for fodder, it is also grown with legumes or grass.

**Land preparation**
Barley has the same general seed bed requirements as wheat. The methods, equipment and timing of operations are also quite similar. It requires a well-prepared, firm and mellow seed bed. Because of its greater drought tolerance, barley may be cultivated under slightly drier conditions than wheat. Cultivation must be designed and timed to minimize water loss while maximizing water infiltration and retention.

**Sowing**
The time and method of sowing are the same as for wheat under both irrigated and rain-fed conditions. Row spacings for both are similar.

Seed rates vary depending on potential soil moisture. With irrigation, seed rates can be about 100 kg/ha. Under conditions of restricted moisture, the seed rate drops to 40 kg/ha to conserve available moisture and to ensure that the plants obtain adequate water throughout the growing season.

Barley should be sown 3–5 cm deep where surface moisture is ample. Deeper sowing (5–8 cm) is practised where there is a deficiency of moisture in the soil.

**Fertilization**
Fertilization must be balanced with the expected available moisture to ensure the highest yields and an efficient use of fertilizers. The dose of fertilizer also depends on the purpose for which the barley is grown. When barley is grown for food or feed, it is desirable to apply fertilizer at higher rates than when barley is grown for malting because the amount of protein in the grain is not as critical in feed barley as it is in malting barley. The protein content of malting barley must be low.

A dose of 80–100 kg N/ha and 40 kg P₂O₅/ha for food or feed barley will provide a balanced nutrition. Where potash is deficient, 40 kg K₂O/ha may be applied. For malting barley the level of nitrogen must be reduced to 60–80 kg/ha but the dose of phosphate should be the same, i.e. 40 kg/ha.

**Water use**
Under favourable growing conditions and normal soil fertility, barley is more efficient than wheat in its use of water. The period between pollination and grain maturation is the most critical stage
in barley and moisture stress during this period causes a considerable reduction in yield. As barley is more drought-tolerant than wheat, good yields of barley can be obtained with fewer irrigations (2–4) but these must be applied at the stages when water is needed most.

**Weed control**
Barley is better adapted to compete with weeds than wheat, as the barley plants grow faster and the stands are thicker than those of wheat. Under rain-fed conditions, however, weeds can cause much damage. The weeds that commonly compete with wheat are also a problem in barley. All the non-grass weeds can be controlled as in wheat with 2,4-D and related phenoxy compounds. Barley is most tolerant of herbicides after it is well-tillered, i.e. at the 5–6 leaf stage when it is 10–20 cm high, but before it has reached early boot stage. Herbicide application to younger plants, or after the plants have started to boot and until seed-set, can severely damage the plants and reduce yields. For controlling grass weeds, the recommendations are the same as for wheat.

**Harvesting and threshing**
In all the developed countries barley is harvested by combine, whereas in other countries the crop is harvested by hand sickle. If barley is to be combine harvested, it should be fully mature and the moisture content of the grain should be 14% or less so as to assure safe storage. Where there is a problem of shattering, the crop can be harvested a little earlier.

Threshing is an important operation in barley production, especially when it is grown for malting. Barley with more than 4% broken kernels is not acceptable as top grade malting barley.

In western countries in recent years, increasing emphasis has been given to harvesting high-moisture barley, i.e. harvesting when grain moisture is from 30–40%. This practice results in yield increases on a dry-weight basis of as much as 30%, with an average increase of more than 15%. Grains with high moisture are harvested where there are special arrangements for drying. High-moisture barley generally has a higher percentage of plump (well-filled) kernels than does barley harvested at maturity. Losses due to shattering are also reduced. Another advantage is that high-moisture crops can be harvested more than a week earlier than normally mature crops.

**Yields**
On a world-wide basis, yields of barley have increased from 1,466 kg/ha in 1961–5, to 1,761 in 1979 and 2,348 in 1989. There is much variation in highest and lowest yields. There was practically no
increase in the average yields of Africa from 1961–5 (706 kg/ha) to 1979 (743 kg/ha) but there has been a considerable increase to 1989 (1,149 kg/ha).

Crop Protection

Diseases
Barley is susceptible to a wide range of fungal diseases, smut being very common.

Covered smut (*Ustilago hordei*): in affected plants the kernels are replaced by a hard mass of black spores encased in a membrane-like sheath. The disease becomes apparent when the plants reach the heading stage and fungal spore masses become evident. The most common control is seed treatment with an organo-mercury seed dressing. This prevents not only covered smut but also leaf stripe (*Pyrenophora gramineae*), an important seed-borne disease which may kill the seedlings or cause partial or complete blindness of the ears.

Loose smut (*Ustilago nuda*) is another serious fungal disease of barley. In plants suffering from loose smut, entire flowers are replaced by masses of spores. When these masses rupture, the spores, carried by wind, infect other plants. As the pathogen is carried inside the seed, chemical seed treatment is ineffective. Hot-water seed treatment can control the disease, as discussed in the section on wheat above.

Rusts: stem rust, leaf rust and stripe rust cause periodic losses. There is no control measure other than to use resistant cultivars if available.

Powdery mildew: of all the cereal crops, barley is the most susceptible to, and suffers most from, powdery mildew. The disease is favoured by conditions such as thick sowing and excessive nitrogen that result in lush vegetative growth. It can be controlled with sulphur dust, but like many other diseases, the best control is the use of resistant cultivars.

Root rots and damping-off diseases also cause losses in barley. BHC (lindane) and carbamates are moderately effective in controlling these diseases.

Insect pests
Chinch-bugs, hessian flies, grasshoppers and aphids are the major pests of barley. Control measures for hessian flies, grasshoppers and aphids are the same as for wheat. For controlling chinch-bugs, management practices that favour the rapid growth of the plant can minimize the damage. The chinch-bugs tend to avoid shady and moist habitats, such as those created by luxuriant vegetative growth.
11
ROOTS AND TUBERS

CASSAVA
(Manihot esculenta Crantz)

Origin and Distribution
The cassava plant originated in north-east Brazil and Central America, and was probably first grown for food by the American Indians in those two areas. Cassava has since spread to various parts of the world so that today it is grown in all parts of the tropics. Most of this spread has occurred within the last four centuries. Cassava was first introduced to Africa in the sixteenth century. It was brought from Brazil by the Portuguese voyagers and was first introduced to West Africa and the Congo basin. The crop was not introduced to East Africa until much later, probably in the eighteenth century.

Area and Production
Cassava is today grown to some extent in practically all tropical countries. It is the most widely distributed of the tropical tuber crops. Tables 11 and 12 give the area and production figures for 1989 for the main producing parts of the world and tropical Africa, respectively. It can be seen that the continent of Africa has a greater area under cassava, and produces more cassava than any other continent. It is followed by Asia and then South America. On a country basis, Thailand, Brazil, Indonesia, Nigeria and Zaire are the greatest producers.

In Africa, significant cassava production occurs in practically every country within the tropical belt but the greatest production is found in West Africa and the Congo basin. Nigeria, Zaire, Tanzania, Mozambique and Ghana are the leading countries for cassava production in Africa. Although there is considerable internal trade in cassava and cassava products in African countries, very little international trade exists in this respect; only Angola and Malawi export any appreciable amount of cassava products.
Table 11  Major world producers of cassava in 1989

<table>
<thead>
<tr>
<th>Region or country</th>
<th>Cassava area (1000 ha)</th>
<th>World cassava area (%)</th>
<th>Production (1000 tonnes)</th>
<th>World production (%)</th>
<th>Yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>World</td>
<td>14987</td>
<td>100</td>
<td>147500</td>
<td>100</td>
<td>9842</td>
</tr>
<tr>
<td>Africa</td>
<td>8346</td>
<td>56</td>
<td>62098</td>
<td>42</td>
<td>7440</td>
</tr>
<tr>
<td>Asia</td>
<td>4053</td>
<td>27</td>
<td>54378</td>
<td>37</td>
<td>13418</td>
</tr>
<tr>
<td>S. America</td>
<td>2380</td>
<td>16</td>
<td>29902</td>
<td>20</td>
<td>12564</td>
</tr>
<tr>
<td>Thailand</td>
<td>1552</td>
<td>10</td>
<td>23460</td>
<td>16</td>
<td>15116</td>
</tr>
<tr>
<td>Brazil</td>
<td>1835</td>
<td>12</td>
<td>23247</td>
<td>16</td>
<td>12548</td>
</tr>
<tr>
<td>Indonesia</td>
<td>1335</td>
<td>9</td>
<td>16581</td>
<td>11</td>
<td>12254</td>
</tr>
<tr>
<td>Nigeria</td>
<td>1300</td>
<td>9</td>
<td>16500</td>
<td>11</td>
<td>12692</td>
</tr>
<tr>
<td>Zaire</td>
<td>2210</td>
<td>15</td>
<td>16300</td>
<td>11</td>
<td>7376</td>
</tr>
<tr>
<td>Tanzania</td>
<td>700</td>
<td>5</td>
<td>6300</td>
<td>4</td>
<td>9000</td>
</tr>
<tr>
<td>India</td>
<td>270</td>
<td>2</td>
<td>5250</td>
<td>4</td>
<td>19444</td>
</tr>
<tr>
<td>Mozambique</td>
<td>580</td>
<td>4</td>
<td>3400</td>
<td>2</td>
<td>5862</td>
</tr>
<tr>
<td>China</td>
<td>227</td>
<td>2</td>
<td>3185</td>
<td>2</td>
<td>14037</td>
</tr>
<tr>
<td>Vietnam</td>
<td>320</td>
<td>2</td>
<td>2900</td>
<td>2</td>
<td>9063</td>
</tr>
</tbody>
</table>

Source: FAO Production Yearbook, 1989

Table 12  Leading producers of cassava in tropical Africa in 1989

<table>
<thead>
<tr>
<th>Country</th>
<th>Cassava area (1000 ha)</th>
<th>World cassava area (%)</th>
<th>Production (1000 tonnes)</th>
<th>World production (%)</th>
<th>Yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nigeria</td>
<td>1300</td>
<td>9</td>
<td>16500</td>
<td>11</td>
<td>12692</td>
</tr>
<tr>
<td>Zaire</td>
<td>2210</td>
<td>15</td>
<td>16300</td>
<td>11</td>
<td>7376</td>
</tr>
<tr>
<td>Tanzania</td>
<td>700</td>
<td>7</td>
<td>6300</td>
<td>4</td>
<td>9000</td>
</tr>
<tr>
<td>Mozambique</td>
<td>580</td>
<td>4</td>
<td>3400</td>
<td>2</td>
<td>5862</td>
</tr>
<tr>
<td>Ghana</td>
<td>415</td>
<td>3</td>
<td>3327</td>
<td>2</td>
<td>8017</td>
</tr>
<tr>
<td>Uganda</td>
<td>340</td>
<td>2</td>
<td>2500</td>
<td>2</td>
<td>7353</td>
</tr>
<tr>
<td>Madagascar</td>
<td>322</td>
<td>2</td>
<td>2250</td>
<td>2</td>
<td>6988</td>
</tr>
<tr>
<td>Angola</td>
<td>500</td>
<td>3</td>
<td>1920</td>
<td>1</td>
<td>3840</td>
</tr>
<tr>
<td>Cameroon</td>
<td>600</td>
<td>4</td>
<td>1530</td>
<td>1</td>
<td>2550</td>
</tr>
<tr>
<td>Côte d’Ivoire</td>
<td>230</td>
<td>2</td>
<td>1300</td>
<td>0.9</td>
<td>5652</td>
</tr>
<tr>
<td>Benin</td>
<td>120</td>
<td>0.8</td>
<td>1002</td>
<td>0.7</td>
<td>8319</td>
</tr>
</tbody>
</table>

Source: FAO Production Yearbook, 1989

**Utilization**

The cassava tuber consists of about 15% peel and 85% flesh. For use as human food, the peel is invariably removed and only the flesh is utilized. Both peel and flesh are utilized if the tuber is to be processed for animal feed. The fresh tuber flesh consists of approximately 62% water, 20–25% starch, 1–2% protein and 1–2% fibre, with traces of fat and minerals. The tuber flesh is relatively rich in vitamin C but has only negligible amounts of other vitamins. Both the peel and the flesh of the tuber, and indeed most parts of the cassava plant, contain significant amounts of two major cyanogenic
glucosides, namely linamarin and lotaustralin. Also present in fresh cassava is the enzyme linamarase which has the ability to hydrolyse these two glucosides to produce hydrocyanic acid (also called prussic acid). This acid is highly toxic to humans and animals. If fresh or partially processed cassava tuber is consumed, hydrolysis takes place and the prussic acid released may be lethal to the consumer. For this reason, the cassava tuber usually has to pass through several detoxification processes before it is safe for human or animal consumption.

The concentration of cyanogenic glucosides ranges from 10–500 mg/kg of fresh tuber, the level of concentration depending on the cultivar. Some cultivars are characterized by a high glucoside content and must be detoxified before consumption. These are sometimes called the bitter cultivars (e.g. TMS 30572; TMS 50207). In others, called sweet cultivars, the level of glucoside is low enough to permit their direct consumption as a vegetable or with minimal processing. LCN 6068 and LCN 30474 are examples of low-glucoside cultivars. It appears, however, that there is a continuous gradation of cultivars from those with extremely low to those with extremely high glucoside content. Within a particular cultivar, the exact level of glucoside can vary slightly, depending on environmental factors. A high level of nitrogen in the soil, for example, tends to increase the level of glucoside in the plant.

For cultivars with very low glucoside content, the cassava tuber can be eaten raw as a salad or snack, roasted, boiled, or boiled and pounded into ‘fufu’. The fresh tuber can also be used to a limited extent for feeding livestock. The cassava tuber is used for human consumption in Africa in three processed forms: the toasted meal (‘gari’), the retted meal, and cassava flour.

‘Gari’ is the most popular form for cassava consumption in West Africa. To make it, the tubers are peeled, washed, grated and packed into bags. The bags are subjected to pressure in order to remove the water, and are left for 2–4 days. This period permits a slight amount of fermentation which further reduces the glucoside content of the meal. At the end of this period the meal is sieved and then toasted in shallow metal pots placed over a fire. Palm oil may be added during the toasting to impart a yellowish colour to the ‘gari’ and to prevent the product from burning during the toasting. The final product may again be sieved and grated. Integrated factories for mechanized ‘gari’ production are now operating in various parts of West Africa.

‘Gari’ is an ideal convenience food since it is dry and can be stored for long periods. It can be eaten dry as a snack or soaked in water and eaten. Most commonly, however, it is poured into boiling water to form a paste (‘eba’) which is eaten with scup or stew.
Rotted cassava meal is made by steeping the fresh tuber (usually after peeling) in water for several days until it is soft. In parts of West Africa, the softened mass is then disintegrated in water, passed through a coarse sieve and then dried out to form a white crumbly meal. This meal can be kept for a few days. When needed, it is boiled, pounded and eaten with soup or stew. In the Congo basin the soft rotten tuber mass is pounded, wrapped in leaves and steamed. The resulting product is called 'chikwangue'.

Cassava flour is made by cutting the peeled cassava tubers into small pieces, drying them in the sun or in an oven, and then milling them to produce a flour. In some cases, the tubers are rotten before they are dried and milled. The flour can be effectively stored for long periods. When needed for consumption, it is prepared by stirring it in boiling water to form a paste which can be eaten with soup or stew.

Cassava leaves are a significant item of diet in Zaire, Congo, Liberia, Sierra Leone, and several other countries in Africa. The leaves must be chopped or crushed, washed in warm water, and then oiled before being consumed. These processes reduce the glucoside content of the leaves and make them safe for consumption. The well-prepared cassava leaf is very nutritious and contains appreciable amounts of proteins, minerals and vitamins.

Cassava tubers for large-scale use in animal feed are usually made into chips and pellets. Chips are essentially dried slices of cassava while pellets are made by grinding the chips and pressing them into cylindrical pieces. Cassava chip and pellet production in Africa is negligible except perhaps in Angola and Malawi.

**Adaptation**

Cassava is essentially a tropical crop. It does best where mean temperatures of 25–29°C occur. Temperatures below 10°C result in the cessation of growth, and it is easily killed by frost. Cassava does best in areas with a rainfall of 1,000–1,500 mm per annum, well distributed throughout the year. It can survive a dry season of 3–4 months and does so by shedding most of its leaves and reducing its growth rate. However, an ample supply of moisture is essential during the first month or two after planting.

Cassava does best on light sandy-loam soils. The fertility of the soil should be high but not excessive, since extremely high soil fertility causes the plant to produce more shoot and less tuber material. The soil must be well drained in order to permit adequate root penetration and discourage tuber rots. For this reason the crop must be grown on ridges or mounds in areas where the water table is
high. Stony soils, saline soils or soils with a hard-pan are unsuitable for cassava cultivation.

Tuber formation in cassava is favoured by short-day conditions. Day lengths greater than 10–12 hrs tend to delay tubering. At low latitudes (i.e. a few degrees north and south of the equator), day lengths encountered during the growing season are short enough to permit and promote easy tubering. At higher latitudes, however, long days experienced during the growing season may sufficiently delay tubering to adversely affect yields.

**Botanical Description**

Cassava (*Manihot esculenta* Crantz) belongs to the dicotyledonous family Euphorbiaceae, a family that also includes the rubber plant (*Hevea brasiliensis*) and the castor plant (*Ricinus communis*). Like most other members of the family, the cassava plant also produces latex. It is a perennial shrub, although under cultivation it is usually harvested after a year or two.

When grown from seed, the cassava plant develops a tap root system typical of dicots. The tap root itself develops from the radicle of the germinating seed. Branch roots arise from the tap root, while adventitious roots may arise from underground stem portions.

In the normal agricultural situation where cassava is propagated by stem cuttings, adventitious roots arise from the stem, giving rise to a fibrous root system. At the initial stage, the internal structure of these roots resembles that of a typical dicot plant, and all the roots participate in the absorption of water and mineral salts. These roots penetrate to a depth of about one metre. During the second month after planting, however, some of the roots lose their fibrous nature and become tuberous. This they do by the formation of secondary xylem tissue, followed by starch deposition in the tissue. Once a root becomes tuberous, it no longer participates actively in the absorption of water and mineral salts. Usually fewer than ten roots in each plant become tuberous, leaving several other roots in the fibrous condition to continue the task of absorbing nutrients.

Starch accumulation in the tuberous cassava root commences near its point of attachment to the stem, and progresses towards the distal portions of the root. As such, the tuber is fattest near its point of attachment to the stem, and tapers gradually towards the distal portion. The extremely distal portion of the tuber is only very slightly thickened, and constitutes the tail. The tuber itself is attached to the stem by a stout woody neck (Fig. 39). The mature cassava tuber may measure up to 1 m in length and weigh up to 2 kg, depending on the cultivar and stage of maturity.
The mature cassava tuber is covered on the outside by a brown corky periderm which is broken at numerous locations (Fig. 40). Internal to the periderm is the cortex which is usually 1–2 mm thick. The peel of the cassava consists of the cortex with the adhering periderm. The flesh of the tuber constitutes the greater bulk and consists essentially of stored starch through which thin vascular bundles ramify at random. A large strand of vascular tissue can also be found running through the very centre of the tuber flesh. These vascular tissues within the tuber flesh are fibrous and are removed to varying degrees when the tuber is processed for food.

The cassava plant has an upright woody stem which may grow to a height of 4 m or more. The pattern of branching varies with the cultivar, but in several cultivars the stem grows for some time and then produces three branches at the same point. Each of these branches again grows for a while and then gives rise to three branches, and so on. The extent of lateral spread of the cassava shoot is dependent on the amount of growth taking place before branching occurs, on the frequency of branching and on the angle of the branches. The degree of lateral spread of the plant is, of course, important in determining the best spacing for the crop. Mature stem portions bear prominent raised leaf scars, and just above each leaf scar is a small axillary bud. The internodal regions between leaf scars may vary in length depending on the cultivar and on environmental conditions existing during the elongation of each particular internode. A favourable environment results in long internodes. If adverse environmental conditions should set in, subsequent internodes on the same plant may be considerably shorter.

Cassava leaves are arranged in a 2/5 spiral phyllotaxis along the stem. Stipules, numbering 3–5, occur at the attachment of each leaf to the stem. The leaf proper is composed of a long petiole and a palmate lamina. The lamina is deeply lobed, but the lobes are not completely isolated from each other, and cannot be considered.
leaflets. The number of lobes varies even among leaves on the same plant. Each lobe possesses a mid-rib which runs its entire length, but the venation of each lobe is reticulate. In most cultivars, the leaf margins are not serrated, and there are no hairs on the leaves. Some cultivars have reddish-coloured petioles and veins, while in others both petioles and veins are green. Each cassava leaf persists on the plant for a relatively short period before it is shed. The length of this period is considerably reduced by adverse environmental conditions such as drought or nutrient deficiency.

Cassava is monoecious, since male and female flowers exist but are borne on the same plant. Indeed the male and female flowers are borne on the same panicle inflorescence which terminates the
branches. Within each inflorescence the male flowers occur at the tip while the female flowers are found towards the base. The female flowers are larger in size than the male. Each male flower has five united sepals, no petals, ten stamens arranged in two equal whorls and an orange-coloured nectar gland. There is no ovary. The female flower has no petals and no stamens. It has five united sepals and an ovary located on a glandular disc. The ovary has three locules, each containing one ovule. There is a single style which subtends a three-lobed stigma.

Flowering in cassava occurs readily in most cultivars, but is rare in a few cultivars. In flowering cultivars, flowers can be seen any time from the second month after planting. In each inflorescence, the female flowers open about a week before the male flowers. This encourages cross-pollination which, for cassava, is carried out mainly by insects.

The cassava fruit matures 3–5 months after pollination. The fruit is a spherical capsule, 1–1.5 cm in diameter, featuring six longitudinal wing-like structures on the outside. When mature and dry, the fruit splits explosively to release the three seeds contained in the three locules.

The seed is covered by a brittle testa which is predominantly grey but mottled with black. There is a large caruncle at the micropylar end. The mature seed is about 1 cm long. Germination of the seed is sometimes difficult, but this can usually be improved by scarification.

Growth cycle
When cassava is propagated by stem cuttings, sprouts and adventitious roots arise on the cuttings in 1–2 weeks. Vigorous shoot growth follows and the leaf area approaches a maximum in about four months. If environmental conditions permit, flowering commences during the second month, while visible tubering starts towards the end of the second month. The crop is mature for harvest in 9–18 months depending on the cultivar. If left unharvested, the cassava plant will continue to grow as a perennial. It reduces its growth and sheds most of its leaves during the dry season, only to resume vigorous growth and leaf production at the onset of the next rainy season.

Cultivation
Cropping systems
Cassava can be profitably grown either intercropped with other species or as a sole crop. Intercrops of cassava with yam, maize, cowpeas and melons are quite common in tropical Africa. When it is
intercropped with a short-season crop such as maize, cowpeas or melons, the usual strategy is to plant the cassava with, or slightly later than, the intercrop so that the intercrop is mature and harvested before the cassava canopy closes in the third or fourth month. When cassava is intercropped with a non-tuber crop such as maize or cowpeas, the cassava invariably occupies the top of the ridge or mound, while the intercrop is planted on the slope. When cassava is intercropped with yam, however, the cassava may be found in a subapical position on the ridge or mound, or in the space between mounds. When cassava is intercropped with yam, the cassava is planted several months after the yam and remains on the field long after the yam has been harvested.

The place of cassava in rotations is governed by some unique attributes of this crop:

* in areas where it is grown, cassava is unique in being the only major arable crop whose growth on the field must span at least portions of two different cropping years. This is because the crop is hardly ever harvested during the same season in which it was planted. As such, cassava is usually the main crop that occupies the field during the dry season.
* cassava does relatively better than most other crops on soils of low fertility
* a cassava plantation is usually not harvested all at the same time, for reasons which will be discussed later. It is therefore difficult to time the planting of the crop which will follow cassava in rotation. It is only when cassava comes before a fallow that this difficulty is avoided.

For these reasons, cassava in shifting cultivation is usually the last crop to occupy the land before it is reverted to bush fallow. Other crops such as yam and maize that require high fertility levels are planted immediately after bush clearing to take full advantage of the high fertility status of the soil. Cassava only comes later when the soil fertility level is too low for the profitable production of the other crops. Even where crop rotation is practised in sole-cropping, the same considerations apply. Cassava usually does not come after the legume crop partly because the high nitrogen content of the soil would lead to a high glucoside content of the cassava and partly because other crops such as cereals may benefit more from the high soil fertility at that time. Cassava can therefore conveniently follow a cereal crop grown after a legume crop.

**Land preparation**

Land preparation for cassava is similar to that for the other tropical tuber crops. The choice of which kind of land preparation to use for
cassava depends on local factors. Where the soil is relatively loose or tillage implements are unavailable, it may be more advisable to plant the cassava on unploughed land after clearing. The use of mounds or ridges is imperative if the soil is relatively compacted or the water table is close to the surface. The use of mounds and ridges also permits easier root penetration and facilitates harvesting. It appears that higher yields are obtained from land which has been ridged or mounded, but this yield advantage must be weighed against the cost of preparing the mounds or ridges.

Cassava is occasionally planted in furrows, but this practice is not very common in Africa. Furrow planting is suited to relatively dry locations and is not recommended for wet regions or heavy soils.

Propagation
Normal commercial propagation of cassava is by means of stem pieces taken from mature portions of the stem. This will be discussed in greater detail later. Propagation by means of true seed is possible, but the resulting plants grow rather slowly and yield poorly. However, the high degree of variability that exists in the seed-grown populations makes this method of propagation extremely valuable in breeding for cassava improvement.

Where there is a need for the rapid multiplication of a cassava clone or cultivar, two other methods of cassava propagation have been found to be very useful. The first is by the use of tender shoot tips. These are plucked from the plant, allowed to produce roots in a mist chamber, and then transplanted to the field. In the meantime the plant or rooted cutting from which the original shoot tips were picked can again produce another batch of shoot tips which can be similarly rooted. The second method for rapid cassava multiplication is by the use of tissue culture techniques. Small blocks of cells derived from the pith or apical meristem are grown in nutrient media to produce large masses of cells. Chunks of these cells can then be transferred to special nutrient media where they differentiate into small cassava plantlets. The plantlets, complete with root and shoot system, can later be transplanted first to greenhouse nurseries and later to the field. Of all the methods of cassava propagation, the tissue culture methods results in the most rapid multiplication. The method has the added advantage of permitting the production of disease-free plants.

Thus of the four methods of cassava propagation, stem cuttings result in the greatest commercial yields, seeds result in great variability for selection during breeding, shoot tips offer rapid multiplication which even the farmer can practise because it is not sophisticated, and tissue culture gives the most rapid multiplication with the possibility of producing disease-free plants.
Planting material
Stem pieces used for cassava propagation should be 15–30 cm long. Cuttings longer than this tend to be wasteful of planting material and cumbersome to handle, while cuttings that are shorter run the risk of not having enough nodes. Theoretically, only one good node (with its axillary bud) is necessary for a cutting to sprout. In practice, however, several axillary buds may be defective or damaged and therefore fail to produce viable sprouts. It is therefore advised that each stem piece should have at least three nodes.

The age of the stem piece is also an important factor. In general, stem pieces obtained from the older parts of the plant establish more rapidly and yield better than those from younger parts. Pieces from very young parts of the stem do not root readily in the field. If planting material is scarce and tender stem pieces must be used, they must first be rooted in a nursery and later transplanted to the field. Where the cassava mosaic disease exists, it may be advisable to avoid obtaining planting material from the very old basal stem portions. These portions are more likely to have been infected with the virus.

The farmer must pay a great deal of attention to the procurement and handling of cassava planting material. As far as possible, the stem cuttings should be obtained from disease-free material. The cuttings should be taken from the parent plants as close to planting time as possible. If the cuttings must be kept for some time before planting, they should be stored in a cool, humid, shady location. In such cases it is more advisable to leave the stem pieces long (1–2 m) and to cut them down to final planting length just before planting. Stem cuttings that have been badly handled or stored for too long usually sprout poorly in the field.

Placement of the cuttings
The spacing used for cassava depends on the cultivar used, the kind of land preparation and the cropping system practised. Where cassava is grown as a sole crop the spacing is usually such as to allow 1 sq m per stand. In this case, a spacing of 1 m on the row and 1 m between rows is the common practice. However, with cultivars whose shoots do not spread appreciably, spacing as close as 80 cm × 80 cm may be used. Where intercropping is practised, the spacing of the cassava usually depends on the density of the other crops in the mixture. This point will be further discussed below.

The spacing of cassava has far-reaching implications for weed control. In a crop with the correct spacing, it should be possible for the shoots of adjacent plants to overlap by the third or fourth month after planting. Thereafter little or no weeding needs to be done,
since the cassava shoots effectively shade and suppress weed growth beneath the canopy. If, on the other hand, the crop has been too widely spaced, canopy closure is considerably delayed and it will be necessary to weed for most of the life of the crop. This situation is prevalent among traditional cassava growers in Africa. Most of them intercrop their cassava with other crops such as maize, yams, vegetables and melons. The spacing of the cassava is usually wide in order to allow space for the other crops. When the intercrops have been harvested and the cassava is left alone on the field, the wide spaces between the cassava stands permit abundant weed growth, so that it is necessary to weed the plot up till the time of harvesting the cassava. This problem could be avoided by ensuring that the cassava is planted closely enough even when the other intercrops are still on the field, or by growing cassava as a sole crop at the appropriate spacing. In sum, therefore, it is better to space cassava too closely than to space it too widely, particularly since the planting material is only a very small fraction of the cost of production.

There are two general methods for planting cassava cuttings. In the first method, the cutting is placed upright with the youngest part of the cutting sticking out above the soil surface. The angle that the stem piece makes with the soil level may vary from 90° (i.e. vertical) to 15° or so, while the fraction of the length of the cutting that remains above the soil usually ranges from a third to a quarter. For a given length of cutting, the fraction of cutting exposed and the angle of placement together determine the depth of the base of the cutting from which most of the roots and tubers will later arise. In the second method of planting, the cuttings are placed horizontally. In this case, the entire cutting lies beneath the soil at a depth of about 10 cm.

Experiments have been carried out in various parts of the world to compare the horizontal and vertical methods of planting cassava (Karnjanakorn, 1968; Takyi, 1974; Krochmal, 1969; Gurnah, 1974). The general finding seems to be that horizontal plantings do better in dry areas while vertical plantings do better in wet regions. For places with an intermediate water supply, either of the two methods would appear suitable.

In most parts of Africa, cassava is planted by hand with the aid of a hoe or macete. Work is being undertaken at various centres on the development of mechanical planters for cassava. In some cases the planters are being designed to plant in the upright position while in other cases the objective is to develop a machine that will open up the soil, drop the cutting in horizontally and cover it up with soil.
**Time of planting**

Cassava can be profitably planted any time from the beginning of the rainy season to about six weeks before the end of the rainy season. Plantings that are made within the last six weeks of the rainy season are unable to establish adequately before the dry season sets in and therefore may fail to survive the dry season. As a rule, cassava should be planted as early as possible in the rainy season, so that the plants have most of the rainy season to grow and establish themselves. Disease and pest considerations may also influence the time of planting. Where the cassava mealy bug or spider mite are prevalent, it is imperative that the cassava be planted very early in the rainy season. These pests are most serious during the dry season, and planting early in the rainy season permits the cassava to make ample growth before the pests become serious.

Many traditional farmers in Africa have a tendency to delay their cassava planting till later in the rainy season. This is partly because the cassava is unusually intercropped, and the farmer waits till the other intercrops are nearly ready for harvest before planting cassava.

**Fertilization**

Cassava has a high requirement for potassium, and the deficiency of this element limits yields in many places. The potassium is usually best supplied in the form of K₂SO₄. The use of muriate of potash (KCl) is discouraged because cassava, like most of the other tropical tuber crops, is sensitive to the chloride ion.

When potassium is available, cassava benefits from moderate applications of nitrogen fertilizer. Excessive nitrogen tends to favour shoot growth at the expense of tuber growth and tends to increase the level of cyanogenic glucosides in the tuber.

Although specific fertilizer recommendations will depend on local soil and plant factors, Kay (1973) has recommended a general application of a 12:12:18 NPK fertilizer at the rate of 450–672 kg/ha. Fertilizer application should be made soon after planting, and if necessary, again two months later before canopy closure. Banding on one side of the row, or spot applications beside each stand are the recommended methods of fertilizer application for cassava. Broadcasting the fertilizer tends to encourage weed growth between the crop stand, while ring application demands too much labour.

Most traditional farmers in Africa grow their cassava without any commercial fertilizer. Fortunately, cassava is able to give reasonable yields even on poor soils. In a few places, farmyard manure and compost are used to fertilize cassava.
Weed control
As already mentioned, weed control in appropriately-spaced cassava is necessary for only the first three months after planting. Where hand or mechanical methods of weed control are employed, the first weeding is done at about four weeks after planting. The second weeding is done at about two months after planting. A third weeding, if necessary, may be done at three months after planting; after that, canopy closure occurs and no further weeding is necessary for the next year or so that the crop occupies the field. When cassava is weeded by hoe, machete or other mechanical means, the tools should not be worked too deeply into the soil so as to avoid damaging the cassava roots.

The fact that cassava requires weeding only at the early stages makes it particularly amenable to chemical weed control. Various herbicides that control weeds before they emerge have been recommended for weed control in cassava. These include diuron (1.6 kg a.i./ha), atrazine (2 kg/ha) and fluometuron (2 kg/ha). If the herbicide effect should wear off and the plot becomes weedy before canopy closure, a single mechanical weeding may be done to supplement the herbicide weed control.

Harvesting
Cassava is ready for harvest when an appreciable amount of starch has accumulated in the tubers. Harvesting too early will result in tubers whose percentage as well as total quantity of starch is too low. On the other hand, harvesting too late produces tubers that are fibrous or woody, and increases the risk of tuber loss due to rotting and pests. Most of the local cassava cultivars grown in Africa are ready to harvest 12–15 months after planting. A few early-maturing cultivars which are ready for harvest in 9 months have recently been introduced to many parts of Africa. For such cultivars, it is possible to plant and harvest the cassava within the same growing season, so that the need for the crop to pass through the long dry season hardly arises. However, many of the early-maturing cultivars suffer the disadvantage that their tubers deteriorate rapidly if left unharvested beyond peak maturity.

The cassava tuber, irrespective of cultivar, cannot be stored in good condition for more than one or two days after harvest. If the harvested tuber is kept for a few days, discoloration of the vascular tissues occurs and the quality of the starch begins to deteriorate. For these reasons, it is customary and advisable that cassava tubers be utilized or processed within a day or two after harvest. This in turn means that cassava is harvested only as rapidly as it can be utilized or processed, so that, unlike most other tropical tuber crops, cassava
on the farm cannot all be harvested as soon as maturity is attained. Harvesting is therefore done piecemeal at a pace dictated by the rate of utilization. Where there is a large processing factory nearby, the pace may be rapid so that the time from maturity till the harvesting of the last batch is relatively short. In the traditional situation, however, the pace of utilization is fairly slow, depending mainly on the rate of cassava consumption by the family, and the harvesting of cassava on a particular field may be spread out over several months. The later batches of tubers are well past maturity, so that the quality is usually low. In addition, rodent damage and the rotting of tubers are rampant in such situations.

The piece-meal harvesting of cassava is also a problem in land utilization on the farm. The cassava crop tends to occupy the land needlessly, and it is not practicable to evacuate it so that another crop can be planted. This problem is partially circumvented in some locations by progressively replanting the field as it is harvested. The crop used for replanting is usually cassava, but other crops may also be used.

In most parts of Africa, cassava is harvested with hand tools. A machete is used to cut off the stem close to ground level. The soil around the tubers is loosened and the tubers can be lifted by pulling on the stub of the stem. Harvesting is easiest in moist loose soil, and most difficult in dry compacted soil. Attempts have been made to produce machines capable of harvesting cassava, but none of these has yet found widespread use in Africa. The machines generally incorporate a forward portion which cuts and removes the cassava shoots. This is then followed by a digging device which lifts the cassava tubers to the surface.

Yields
Average yields of cassava in Africa are about 7 tonnes of fresh tuber per hectare. On a world basis, yields average about 10 tonnes/ha, while in South America yields average about 13 tonnes/ha.

Crop Protection

Diseases
The most significant diseases of cassava are cassava bacterial blight and cassava mosaic disease.

Cassava bacterial blight (CBB), caused by Xanthomonas manihotis, was introduced to Africa from South America in the 1960s or 1970s and has since spread to most of the important cassava-producing areas of Africa. The disease is characterized by angular leaf spots and wilting of the leaves. The young sprouts die back, then new sprouts which arise from the basal portions also die back, and
so on. The disease is spread through infected cuttings, by splashing rain and mechanically by insects. It can be controlled by the use of disease-free cuttings, the burning of diseased plant residues, and the use of resistant varieties such as TMS 50395 and TMS 50193.

Cassava mosaic disease has been present in nearly all cassava-growing countries of Africa for several decades. It causes yellowish chlorosis and distortion of the young leaves, although the entire plant rarely dies (Fig. 41). The disease is caused by a virus which is spread by the whitefly, *Bemisia tabaci*. It can be controlled by the use of disease-free cuttings, and the use of resistant varieties such as
TMS 50395, TMS 52026 and TMS 51077. Heat-treating the cuttings before planting may sometimes be beneficial since it inactivates the virus. Finally, attempts can also be made to control the white flies with insecticides for the first six months after planting.

**Insect pests**

The insects which seriously damage cassava are mealy bugs, green spider mites and variegated grasshoppers.

**Cassava mealy bugs** are relatively new to Africa, having been introduced from South America within the last two decades. Within this time they have spread rapidly, and now occur in most of the cassava-producing countries of Africa. Mealy bug infestation results in stunted growth and extremely shortened internodes near the shoot apex. Leaves wilt and drop; the shoot dries up and has the appearance of a candlestick. White masses of mealy bugs can be seen near the shoot tip.

No satisfactory control measures for the mealy bug have yet been worked out. However, since the pest is most serious during the dry season, it is recommended that cassava be planted early in the rainy season so that the crop can make appreciable growth before the dry season. Attempts are being made at various research centres to produce cassava varieties resistant to mealy bugs, or to identify natural predators which can be used to control them.

**Cassava green spider mites** are a serious pest. They infest the growing points and cause stunting and deformation. Like the mealy bug, the green spider mite is most serious during the dry season, and similar control measures are used.

**Variegated grasshoppers** (*Zonocerus variegatus*) damage the cassava plant by feeding on the shoot. The damage is worst during the dry season when the grasshoppers are most numerous and when cassava is one of the few arable crops in the field. The grasshoppers are best controlled through a large-scale regional effort involving large areas.
YAMS

Yams are members of the genus *Dioscorea* which produce edible tubers. They are monocots. Although more than ten species in this genus are used for food in various parts of the world, only six species are extensively cultivated in Africa.

**Origin and Distribution**

The white guinea yam (*Dioscorea rotundata*) is grown on a greater hectarage and produced in larger quantities than any other kind of yam in the world. It originated in West Africa and remains the predominant kind of yam grown there. It is characterized by firm white tuber flesh, heart-shaped leaves with pointed tips, and a spiny stem which is circular in cross section.

The water yam (*Dioscorea alata*) is grown in practically all parts of the tropics where, except in parts of Africa, it is the predominant kind of yam grown. It originated in south-east Asia, and first reached Africa at the East African coast. By the sixteenth century it had been introduced to West Africa. The tuber flesh is generally white but loose in texture. The stem has four or more rows of wings running its entire length, so that the stem is star-shaped in cross-section and usually devoid of spines. The leaf petioles also have wings. The leaves are heart-shaped and pointed, but are usually larger than those of the white guinea yam.

The yellow yam (*Dioscorea cayenensis*) originated in West Africa and is not grown very extensively outside the area. The tuber flesh is usually yellow, while the corm attached to the tuber is larger than that of most other yams. The leaves are dark green in colour and usually broad. The yellow yam requires a longer season for maturity than most other yams.

The trifoliate yam (*Dioscorea dumentorum*) originated in tropical Africa, and is today cultivated extensively only in West Africa. It differs from most of the other kinds of yam in having trifoliate leaves and hairs on the stems and leaves. Unlike the previous three kinds of yam, which twine to the right, the trifoliate yam twines to the left, i.e. it approaches the support keeping to the left. The tuber is large, coarse, irregularly-shaped and somewhat bitter, so that it requires long periods of steeping in water and boiling before it is eaten.

The chinese yam (*Dioscorea esculenta*) originated in South-East Asia. It was first cultivated in China several centuries ago and today it is extensively grown mainly in South-East Asia, the Pacific and the West Indies. It is relatively new to Africa, and its cultivation there remains quite limited. The stem twines to the left, and unlike most other kinds of yam, each plant produces a cluster of several small
tubers rather than one or two large ones. The tuber has a higher sugar content than those of other yams and is therefore sweet-tasting.

The aerial yam (Dioscorea bulbifera) originated in both Africa and Asia. The plant characteristically produces numerous aerial tubers or bulbils which are used for food. It also produces some edible underground tubers. The relative amounts of bulbil and underground tuber vary from cultivar to cultivar.

**Area and Production**

West Africa is the most important area for yam production in the world. Over 90% of global yam production comes from this region. Nigeria alone produces about 68% of the world's yams, with Côte d'Ivoire, Benin, Ghana and Togo following in that order (Table 13).

<table>
<thead>
<tr>
<th>Region or country</th>
<th>Yam area (1000 ha)</th>
<th>World yam area (%)</th>
<th>Production (1000 tonnes)</th>
<th>World production (%)</th>
<th>Yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>World</td>
<td>2537</td>
<td>100</td>
<td>23459</td>
<td>100</td>
<td>9239</td>
</tr>
<tr>
<td>Africa</td>
<td>2399</td>
<td>94</td>
<td>22286</td>
<td>95</td>
<td>9282</td>
</tr>
<tr>
<td>Nigeria</td>
<td>1500</td>
<td>59</td>
<td>16000</td>
<td>68</td>
<td>10667</td>
</tr>
<tr>
<td>Côte d'Ivoire</td>
<td>250</td>
<td>10</td>
<td>2370</td>
<td>10</td>
<td>9480</td>
</tr>
<tr>
<td>Benin</td>
<td>89</td>
<td>4</td>
<td>1049</td>
<td>4</td>
<td>11792</td>
</tr>
<tr>
<td>Ghana</td>
<td>217</td>
<td>9</td>
<td>742</td>
<td>3</td>
<td>3605</td>
</tr>
<tr>
<td>Togo</td>
<td>38</td>
<td>1</td>
<td>400</td>
<td>2</td>
<td>10525</td>
</tr>
<tr>
<td>Zaire</td>
<td>30</td>
<td>1</td>
<td>265</td>
<td>1</td>
<td>8833</td>
</tr>
<tr>
<td>Ethiopia</td>
<td>62</td>
<td>2</td>
<td>250</td>
<td>1</td>
<td>4032</td>
</tr>
<tr>
<td>Chad</td>
<td>25</td>
<td>1</td>
<td>240</td>
<td>1</td>
<td>9600</td>
</tr>
<tr>
<td>Cameroon</td>
<td>56</td>
<td>2</td>
<td>230</td>
<td>1</td>
<td>4107</td>
</tr>
<tr>
<td>Centr. Afr. R.</td>
<td>46</td>
<td>2</td>
<td>230</td>
<td>1</td>
<td>5044</td>
</tr>
<tr>
<td>Brazil</td>
<td>23</td>
<td>0.9</td>
<td>210</td>
<td>0.9</td>
<td>9130</td>
</tr>
</tbody>
</table>

Source: FAO Production Yearbook for 1989

Within West Africa, production occurs in the northern forest and southern savanna zones. Further north, the rainy season is too short, and further south the soils are waterlogged and there is too much cloud cover for economical yam production. The white guinea yam is the predominant yam grown in West Africa. Elsewhere in Africa, significant quantities of yam are produced in Zaire, Ethiopia, the Central African Republic and Sudan.

South America (mainly Brazil and Colombia) and the West Indies (mainly Martinique and Jamaica) follow West Africa in yam production. The major species grown in the West Indies is the water
yam. Appreeciable yam production also occurs in Japan, Papua New Guinea and the smaller islands of the South Pacific.

Utilization
The freshly harvested yam tuber consists of about 70% water, 25% starch, 1–2% protein and only traces of sugars and vitamins. The most common forms of yam consumption are as boiled yam and pounded yam. Boiled yam is produced by boiling the tubers (before or after peeling) in water. It is consumed with oil, stew or vegetables. Pounded yam is made from boiled yam by pounding the boiled yam in a mortar to produce a thick paste. Balls of this paste are dipped in soup or stew before being eaten. Occasionally yams may be roasted, fried or baked.

Processed forms in which yam can be stored are also found in Africa. The most common is yam flour. This is made by drying thin slices of the peeled tuber and milling the dried pieces to produce a flour which can be stored dry for several months. When needed for consumption, the flour is stirred in boiling water over a fire to produce a paste. The paste is similar to pounded yam, and is eaten in the same way. Other processed forms of yam include yam chips, which are used as a snack, and yam flakes. The flakes, when stirred with boiling water, reconstitute into a product identical to pounded yam.

There is very little international trade in yams, even though significant trade in the commodity occurs within the various producing countries.

The cultivation of yams, particularly in West Africa, is surrounded by considerable ritual. At each stage of the production process, rituals and traditional religious practices are performed for the success of the crop. Then, as crop maturity approaches, a date is fixed for the new-yam festival. Normally, farmers may not harvest or consume new yams before that date. On the appointed day there is considerable merry-making and ritual worship to usher in the new yams. It is noteworthy that no other crop in Africa is associated with a greater amount of social and cultural activity than the yam.

Adaptation
Yams grow best at temperatures of 25–30°C and their cultivation is essentially restricted to the tropics. Their growth is considerably retarded at temperatures below 20°C. Since they require 6–9 months to mature on the field, it is essential that the rainy season lasts at least as long, unless supplementary irrigation can be provided. A well-distributed rainfall (or water supply) of 1,500 mm per annum is adequate for yam production. However, dry spells of up to a month during the growing season need not severely reduce yields. Tuber
formation in yams is promoted by short-day conditions, but low light intensity or shade during the season tends to reduce yam yields severely.

Compared with other tropical tuber crops, yams require soil of high fertility. Loose loamy soils are best as heavy clays tend to be waterlogged and result in tuber rots and difficult harvesting. Gravelly or rocky soils tend to hinder tuber penetration.

**Botanical Description**

Yams have a fibrous root system confined mostly to the top 30 cm of soil. In species where the stem is very spiny, some spines may also be present on the roots. In many species, a few thin roots can also be found on the body of the tuber.

The yam tuber is neither a stem nor a root tuber. Detailed morphogenetic studies indicate that it develops from the hypocotyl region. Unlike typical root tubers such as cassava and sweet potato, it does not develop by the enlargement of pre-formed roots and it lacks the analogue of a root cap at its extreme tip. Unlike typical stem tubers such as the potato, it does not possess a terminal bud at its growing point, is devoid of scale leaves, and axillary buds ('eyes') are absent from the general tuber surface.

The general morphology of the yam tuber is shown in Fig. 42. The tuber itself is attached to a corm which in turn is attached to the main

---

![Diagram of yam tuber morphology](image)

**Fig. 42** General morphology of the yam tuber
roots and stem of the plant. Indeed, the corm serves as the central
point of origin of the roots, stem and tuber of the plant. The corm is
woody and possesses dormant buds, but the tuber itself is devoid of
buds. The part of the tuber nearest the corm is called the head, while
the most distant part is the tail. A few thin roots may occur on the
tuber surface.

The outermost layer of the tuber is a corky layer which serves to
protect it from damage and desiccation. Just beneath the cork is a
very thin cortex. Beneath the cortex lies a thin but significant layer of
meristematic cells whose activity is responsible for the sprouting of
planted tuber pieces. The central portion of the tuber, which con-
stitutes most of its bulk, is composed of storage parenchyma inter-
spersed with vascular bundles.

The yam stem is a thin twining structure. The direction of twining
around a support depends on the yam species. D. rotundata, D.
cayenensis and D. alata keep to the right when approaching a
support and therefore twine in a clockwise direction going upward.
D. dumetorum, D. bulbifera and D. esculenta keep to the left when
approaching a support.

The stems in most yams are more or less circular in cross-section
but in D. alata the stem is usually star-shaped in cross-section,
because the angles of the stems are extended to form wing-like
structures running the entire length of the stem. Spines are com-
monly found on the stems of the white yam, yellow yam, trifoliate
yam and Chinese yam, while hairs are present on the stem of the
trifoliate yam.

For most kinds of yams, the leaves are simple, net-veined, devoid
of hair and more or less heart-shaped. The leaves are generally green
although the leaves of some cultivars of D. alata may be purplish,
especially when young. Leaf arrangement on the stem is either
opposite or alternate. Dioscorea dumetorum differs from most other
yams in having trifoliate leaves with hairs on both the petiole and
the lamina.

Yams are usually dioecious, producing male and female flowers
on different plants, although a few cases of male and female flowers
being born separately on the same plant have been reported. The
female flowers are borne in spikes arising from the leaf axils, while
the male flowers are much smaller and borne in panicles. Each
female flower has three sepals, three petals and an inferior ovule
with three locules; each male flower consists of three sepals, three
petals and three or six stamens. The pollen grains are sticky, and
pollination is by insects, despite the inconspicuous nature of the
flowers. The yam fruit is a capsule with three locules and a maxi-
mum of two seeds per locule. The seed is flat, and part of the testa is
usually extended into a wing-like structure that aids in seed dispersal. A relatively large endosperm surrounds the embryo of the seed. The seed usually goes through a dormancy period of 3–4 months before it can germinate.

Flowering and seed production in yams are extremely irregular. Some species such as *D. alata* flower only rarely, while others such as *D. cayenensis* produce only male flowers and therefore cannot produce seeds. Even for species where flowering is common, a sizeable proportion of the plants on the field complete their annual growth cycle and die without producing any flowers. Where flowers are produced, pollination is poor and ovule abortion is

![Graph](image)

Fig. 43 Growth phases of the yam plant
high. As a result, only a small quantity of good seed can result from the average yam farm.

**Growth cycle**
The growth cycle of the yam plant can be divided into four phases (Fig. 43). The first phase commences as soon as the planted tuber piece sprouts. It is characterized by very active root proliferation and a moderate amount of vine (stem) elongation. About 6 weeks after sprouting, the second phase commences. In this phase, the rate
of root proliferation declines, vine growth continues and leaf expansion commences. Towards the end of this phase, at about the tenth week after sprouting, tuber initiation occurs, and for cultivars that produce flowers, flowering commences. The third phase lasts from about the tenth to the eighteenth week after sprouting. During this phase further root and vine growth are negligible. The total leaf area increases for some time and then remains stable, while active increase in tuber bulk occurs throughout this phase. The fourth and final phase of the growth cycle is marked by large-scale senescence of the entire shoot. No further increase in tuber bulk occurs during or after this phase and the tuber is ready to harvest at this time. Tuber harvested soon after shoot senescence do not sprout readily if planted immediately but go through a period of dormancy. The level of dormancy, characterized by the duration from planting to sprouting, decreases with time in storage. By six months after harvesting, the dormancy has reached its lowest level and planted tubers or tuber pieces will sprout readily.

Cultivation

Cropping systems
When shifting cultivation is practised, yam is usually the first or one of the first crops to be planted after the land is cleared from bush fallow. This is because of its high fertility requirements, its relatively long growing season, and the high value that farmers attach to the
yam crop. In continuous cropping, yam again usually occupies a position in the rotation where it can benefit from high soil fertility. It usually does best if it follows a legume crop in the rotation, but care should be taken to ensure that it does not follow a legume crop that favours the build-up of nematodes in the soil.

Land preparation
Land preparation for planting yams is the same as that already described for planting cassava. After the land has been cleared, the soil is made into ridges or mounds (see Chapter 8). Occasionally, yams are planted on the flat after ploughing, or in holes dug in unploughed land. However, yams grown on the flat or in holes yield
lower and are more difficult to harvest than those grown on ridges and mounds.

**Planting**

Yams are normally propagated using tuber material. The piece of tuber that is used for planting is called a sett. It may be a small whole tuber, or a piece of tuber derived from the head, middle or tail region of a larger tuber. The preference for a kind of sett as planting material depends on the rapidity with which it will sprout, and how prone it is to rotting after planting. As a rule, the head portions of yam tubers sprout more readily than the middle and tail portions. On the other hand, whole tubers have no cut surface and are therefore less prone to rotting when planted than head, middle or tail portions. For these reasons, whole tubers are preferred to head portions, which in turn are preferred to middle and tail portions.

As a rule, the larger the sett weight used, the greater the tuber yield obtainable from the resulting plant. This is because large setts sprout more readily, establish more quickly, and give rise to more vigorous plants with a larger total leaf area. Very small setts are therefore disadvantageous because they result in very small tubers which have low market value. However, very large setts are also disadvantageous because they result in low multiplication ratios (i.e. weight of tuber yielded divided by weight of sett planted). Very large setts are therefore wasteful of planting material. For commercial yam production, setts weighing 200–400 g are normally used.

Where yam is grown as a sole crop, it is generally spaced 1 m apart on rows that are also 1 m apart. However, where staking is not intended, it may be advisable to adopt a closer spacing so that adjoining plants can creep together. Where yam is intercropped with other crops, the spacing between yam plants will depend on the number and intensity of the intercrops.

The yam sett is planted in the soil at a depth of about 10 cm. Setts that are planted too shallowly run the risk of being exposed by animals or rain splash, or being damaged by heat. Indeed, if planting is done during a period of unsteady rains, it is essential to place a layer of mulch over the soil above the sett in order to protect it from excessive heat and desiccation.

The exact month of planting varies from place to place, but there are generally two kinds of practice in Africa with respect to the time of planting yam. Some farmers plant their yams at the onset of the dry season, so that the sett spends the dormancy period in the soil and sprouts at the beginning of the rainy season. For dry season planting, mulching is imperative. Other farmers plant at the beginning of the rainy season, using tubers that have been stored in a barn
through the dry season. As a rule, the rainy season planting should be done as early as possible after the season begins. Once the rainy season has fully commenced, the later the planting, the lower the expected yields. Mulching is often not required for rainy-season planting. In parts of West Africa, dry season planting takes place in October or November while rainy season planting takes place in March or April.

In dry season planting, emergence occurs 3–4 months after planting, while in rainy season planting it occurs in 1–2 months. In practice, yam emergence is hardly ever uniform. There is usually a gap of several weeks between the early emergers and the late emergers in a particular field. When the shoots are about 1 m long they are unable to support themselves and staking is normally done at this time. A single erect stake of about 2 m long may be provided for each stand, or the inclined stakes from three or four adjacent stands may be brought together at the top to form a pyramid. Another common method of supporting yams is the trellis method in which the vines are allowed to climb up ropes hanging from a suspended length of wire. A combination of stakes and the trellis method is found among the yam farmers of Ogbaru and neighbouring districts of the lower Niger River in Nigeria. Here, stakes are first placed and then the stakes on a particular field are all held together by a network or ropes running from one stake to another. The ropes provide additional climbing space for the yams as well as holding the stakes together against high winds.

The benefits of staking in yam production are three-fold:

* it results in greater yields due mainly to the greater display of leaves that occurs in staked plants

* it permits the shoot to be kept away from the soil surface, thereby promoting air circulation and reducing the incidence of foliar disease

* It makes it easier to move through the field to perform farm operations such as weeding or fertilizer application.

Staking, however, remains a major problem in yam production. It is very expensive and laborious, yet the prospects of its being mechanized are very remote. For these reasons, vigorous efforts have been made to devise agronomic packages that will permit profitable yam production without stakes (Onwueme and Fadayomi, 1980). It should be pointed out here that in the drier areas of the yam-producing zone, the growing of yams without stakes is the common practice. This is partly because the high light intensities (less frequent cloud cover) and the relatively dry weather
permit reasonable yam yields even without the additional leaf display provided by staking. In part too, the practice of not staking yams in the drier regions has evolved out of expediency, since there is very little forest from which to obtain wooden stakes in those regions.

Weed control
Weed control in yams is another operation which takes up a considerable part of the time of traditional yam farmers. Most of them weed their fields three or four times during the season, using hoes or machetes. Experiments have shown that yams are most sensitive to weed competition between emergence and the time of tuber initiation in the third or fourth month after emergence. It is therefore essential that adequate weed control is maintained at least during this period.

The use of herbicides to control weeds in yam is not very widespread in Africa, but it is increasing. The most commonly recommended herbicides are diuron (3–3.5 kg/ha), atrazine (3.5 kg/ha) and ametryne (3–4 kg/ha). These are all effective on weeds before they emerge and may therefore be applied soon after the yams are planted. In other cases, the application may be delayed for 2–3 weeks after planting, i.e. until just before yam emergence begins. In such cases, it may be necessary to mix one of the pre-emergence herbicides above with paraquat, which will kill the weeds that have already emerged.

In most cases, herbicides applied at or just after planting are unable to control weeds for the entire growing season of the yam crop. Later in the season it may therefore be necessary to resort to supplementary hand-pulling or herbicides to control weeds. If the yams are grown without stakes and at close spacing, it may be possible to eliminate the need for late-season weed control.

Fertilization
Most traditional yam farmers practising shifting cultivation do not fertilize their yam fields. However, with the shortening of the bush fallow period and the concomitant decline in the general levels of soil fertility, the use of fertilizers has continued to increase. Compost and farmyard manure, produced and used at the village level, have been found to result in improved yam yields. Commercial fertilizers are also in common use. Apparently yams respond well to nitrogen and potassium fertilizers, but very little to phosphorus. The exact fertilizer formulation and quantity used will depend on the local soil conditions, but generally yams are sensitive to chloride and it is advisable to apply potassium as the sulphate rather than as the chloride. When inorganic fertilizers are used, it is recommended
that the dose be split: the first application is made about a month after emergence, while the second is made during tuber bulking about 3 months after emergence. Where composts or slow-release urea fertilizers are used, a single application may suffice. Fertilizer placement in yam production is by spot, band, or ring application. A spot application, 15 cm away on one or both sides of the plant, is preferred because of the rapidity with which it can be done. The band placement for ridge-grown yam, and the ring application for mound-grown yam, are sometimes practised, each time keeping the fertilizer 10–15 cm away from the plant.

**Harvesting**

Two kinds of practice exist with respect to the timing of the yam harvest. In **double harvesting**, each yam plant is harvested twice. A first harvest is done at about 5 months after emergence. During this harvest, the farmer digs carefully to expose the tuber without damaging the plant’s roots. The tuber is then severed from the rest of the plant at a point just below the corm. The tuber is removed and the roots are covered up again with earth. The plant continues to grow and later produces a new tuber. After the plant has finally died at the end of the season, the second harvest is done. The tuber recovered at the second harvest is firmer in texture and more irregular in shape than that from the first harvest. **Single harvesting** involves waiting until the end of the season when the vines have died, before harvesting the yams. Each plant is therefore harvested just once.

Detailed comparisons have been made between double harvesting and single harvesting (Onwueme, 1978). Double harvesting has the advantages of making the new crop available for consumption earlier in the season, and of producing excellent planting material at the second harvest. However, double harvesting also has several disadvantages compared to single harvesting. Firstly, double harvesting requires at least double the labour for the harvesting operation, yet experiments have shown that the combined yields of the two harvests are no higher than that obtainable by single harvesting. Secondly, the first harvest of the double harvest is extremely delicate because of the need to avoid root damage. As such, prospects of mechanizing this operation are extremely remote. Thirdly, double harvesting produces tubers that are poorer for consumption than the tubers from single harvesting. The tubers from the first harvest are often watery and not completely mature, while tubers from the second harvest are woody in the head region. All told, double harvesting is appropriate only for traditional agriculture and will,
with time, be progressively replaced by the practice of single harvesting.

The mechanical harvesting of yams is not a common practice at present, but it is certainly desirable for the future. Efforts are in progress in the West Indies and in West Africa towards developing mechanical harvesters for yams. Selection is being carried out for cultivars with globose tubers (e.g. TDa 291), firm skin, and the ability to yield well without staking. For mechanical harvesting the mean size of each tuber should not be very large, but this can easily be achieved by reducing the sett weight used for planting.

Yields
The average yields of fresh yam tuber in Africa are about 10 tonnes/ha. Higher or lower yields may be obtained depending on the cultivar and on the level of management. In the West Indies, yields are generally higher than in Africa, ranging from 11–14 tonnes/ha.

Storage
Most of the yams produced in Africa are stored in the form of the fresh tuber. There are three common methods of storing the tuber: in barns, on platforms and underground. The barn is the commonest form of yam storage in West Africa. It is erected in an open place and consists essentially of a series of vertically-oriented poles to which the yams are tied with rope (Fig 47). In platform storage, the yams are laid horizontally on an elevated platform; while in underground storage the tubers are placed together in a large ditch and then covered with soil or dry vegetation. Whichever method of yam storage is adopted, it is essential that the tubers should be well aerated and well shaded. In addition, the stored tubers should be inspected frequently so that rotting ones can be removed, and the sprouts can be removed from those that begin to sprout.

The main causes of loss during yam tuber storage are rotting, tuber respiration and tuber sprouting. Respiration and sprouting utilize the stored material of the tuber. Appreciable moisture loss from the tuber also occurs during storage. The use of cold storage for yam tubers would be advantageous in reducing storage losses due to rotting, sprouting and respiration. However the practice is at present limited by the high cost of continuous refrigeration and by the fact that yams stored at temperatures below 10°C tend to become brown and unsuitable for consumption. A promising advance in yam storage technology is the report that gamma irradiation can prolong the storability of yam tubers (Adesuyi, 1973, 1976).
Crop Protection

Diseases
The main diseases affecting yams are tuber rots and anthracnose.

Tuber rots, caused mostly by fungi, are among the most serious diseases of yams. The rots may infect the tubers either in the field or during storage. The soft rots are caused mainly by *Penicillium* spp., *Fusarium* spp. and *Botrydiplodia* spp., while the dry rots are caused by *Rosellinia* and *Sphaerostilbe*. The rots can be controlled by avoiding tuber wounding during harvest and by good soil aeration in the
field. Occasionally, treatment of the sett with fungicide or alkaline material before planting may reduce the incidence of tuber rots in the field.

**Anthracnose disease** is particularly severe when it attacks *Dioscorea alata*. Leaf necrosis and death of the entire plant occur, so that the yield losses are considerable. The use of resistant varieties such as TDa 291 and Aponmapondenu, appears to be the best control measure.

**Nematodes**
The yam *nematode* (*Scutellonema bradys*) and the *root-knot nematode* (*Meloidogyne* spp.) also attack yam. The former causes
damage to the meristematic region just beneath the tuber skin, so that affected tubers perform very poorly if used as planting material. The root-knot nematode, on the other hand, gives the tuber a warty appearance. The nematodes can be controlled by effective crop rotations which include non-susceptible crops. Occasionally, nematicides may be used to fumigate the soil, but this is not always economical.

Insect pests

Yam beetles (*Heteroligus* spp.) are a major pest of yam, particularly in West Africa. The beetles do considerable damage to the tubers in the field, leaving deep hemispherical holes on the body of the tuber. They are best controlled by dusting the planting sett with insecticides such as aldrin and lindane (Gamma BHC or Gammalin).
ROOTS AND TUBERS

SWEET POTATOES
(Ipomoea batatas (L.) Lam)

Origin and Distribution
The sweet potato originated in Central America, and the northwestern part of South America. It was cultivated there for several centuries before it was introduced to Europe in the sixteenth century. It probably came to Africa from Europe during the voyages of discovery.

Today sweet potatoes are grown in most parts of the tropics and the warmer temperate regions. Asia produces over 90% of the world’s sweet potatoes, with China alone accounting for over 85% of world production. Other important producing countries on a world basis are Vietnam and Indonesia (Table 14).

<table>
<thead>
<tr>
<th>Region or country</th>
<th>Sweet potato area (1000 ha)</th>
<th>World sweet potato area (%)</th>
<th>Production (1000 tonnes)</th>
<th>World production (%)</th>
<th>Yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>World</td>
<td>9247</td>
<td>100</td>
<td>133234</td>
<td>100</td>
<td>14408</td>
</tr>
<tr>
<td>Asia</td>
<td>7597</td>
<td>82</td>
<td>123600</td>
<td>93</td>
<td>16269</td>
</tr>
<tr>
<td>Africa</td>
<td>1184</td>
<td>13</td>
<td>6105</td>
<td>5</td>
<td>5155</td>
</tr>
<tr>
<td>S. America</td>
<td>151</td>
<td>2</td>
<td>1549</td>
<td>1</td>
<td>10271</td>
</tr>
<tr>
<td>N. America</td>
<td>189</td>
<td>2</td>
<td>1324</td>
<td>1</td>
<td>7014</td>
</tr>
<tr>
<td>China</td>
<td>6465</td>
<td>70</td>
<td>114000</td>
<td>86</td>
<td>17633</td>
</tr>
<tr>
<td>Vietnam</td>
<td>350</td>
<td>4</td>
<td>2000</td>
<td>2</td>
<td>5714</td>
</tr>
<tr>
<td>Indonesia</td>
<td>232</td>
<td>3</td>
<td>2196</td>
<td>2</td>
<td>9095</td>
</tr>
<tr>
<td>Uganda</td>
<td>310</td>
<td>3</td>
<td>1830</td>
<td>1</td>
<td>5806</td>
</tr>
<tr>
<td>India</td>
<td>170</td>
<td>2</td>
<td>1330</td>
<td>1</td>
<td>7941</td>
</tr>
<tr>
<td>Japan</td>
<td>63</td>
<td>0.7</td>
<td>1339</td>
<td>1</td>
<td>21111</td>
</tr>
<tr>
<td>Rwanda</td>
<td>113</td>
<td>1</td>
<td>810</td>
<td>0.6</td>
<td>9662</td>
</tr>
<tr>
<td>Brazil</td>
<td>76</td>
<td>0.8</td>
<td>750</td>
<td>0.6</td>
<td>9662</td>
</tr>
</tbody>
</table>

Source: FAO Production Yearbook for 1989

Africa accounts for only about 5% of world production of sweet potatoes. Even though production occurs in nearly all countries, it is only in parts of Central and East Africa that it forms a major item of diet (Table 15).

Utilization
The fresh tuber of the sweet potato consists of about 60–70% water, 15–25% starch, 1–2% protein and 1–2% sugars. A good proportion of the starch is converted to maltose during cooking, thus imparting additional sweetness to the cooked tuber. The tuber also contains significant amounts of vitamins and minerals. The vitamins are
Table 15  Leading producers of sweet potatoes in tropical Africa in 1989

<table>
<thead>
<tr>
<th>Country</th>
<th>Sweet potato area (1000 ha)</th>
<th>World sweet potato area (%)</th>
<th>Production (1000 tonnes)</th>
<th>World production (%)</th>
<th>Yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uganda</td>
<td>310</td>
<td>3.4</td>
<td>1800</td>
<td>0.4</td>
<td>5806</td>
</tr>
<tr>
<td>Rwanda</td>
<td>113</td>
<td>1.2</td>
<td>810</td>
<td>0.6</td>
<td>7168</td>
</tr>
<tr>
<td>Kenya</td>
<td>42</td>
<td>0.5</td>
<td>550</td>
<td>0.4</td>
<td>13095</td>
</tr>
<tr>
<td>Madagascar</td>
<td>105</td>
<td>1.1</td>
<td>475</td>
<td>0.4</td>
<td>4524</td>
</tr>
<tr>
<td>Burundi</td>
<td>32</td>
<td>0.6</td>
<td>426</td>
<td>0.3</td>
<td>8159</td>
</tr>
<tr>
<td>Zaire</td>
<td>74</td>
<td>0.8</td>
<td>372</td>
<td>0.3</td>
<td>5024</td>
</tr>
<tr>
<td>Tanzania</td>
<td>200</td>
<td>2.2</td>
<td>340</td>
<td>0.3</td>
<td>1700</td>
</tr>
<tr>
<td>Nigeria</td>
<td>20</td>
<td>0.2</td>
<td>260</td>
<td>0.2</td>
<td>13000</td>
</tr>
</tbody>
</table>

Source: FAO Production Yearbook for 1989

mainly carotene, ascorbic acid and the B complex vitamins. The cultivars with yellowish flesh are particularly rich in ascorbic acid. The important minerals contained in the tuber are potassium, sodium, chloride, phosphorus and calcium.

Most sweet potatoes produced in Africa are consumed by boiling, baking, frying or roasting the unprocessed tubers. Whenever possible, it is best to cook the tuber before peeling since this permits some of the vitamins and minerals which are present in the peel to permeate into the edible flesh. Sweet potato flour is made by drying thin slices of the tuber and then milling the dried slices. This form of utilization is not very common in Africa. Far more common is the use of sweet potato leaves for human consumption. The young leaves are particularly rich in protein, minerals and vitamins. They are usually boiled before being eaten.

Both the tuber and shoot can serve as livestock feed. The tuber can be fed to livestock either in the fresh form or in the form of chips. Similarly, the shoot can be fed fresh or it can first be made into silage. This is one economical way to utilize the vines left on the field after harvest. The use of sweet potato tubers for the industrial production of starch, sugars and alcohol is not widespread, partly due to the existence of more economical sources of these products. International trade in sweet potatoes is relatively small. Trinidad and Tobago is a new importer while exporting countries include Japan and Egypt. In tropical Africa, most of the crop is consumed within the country of production.

Adaptation
Sweet potatoes are a warm-weather crop and grow best at temperatures above 24°C. The crop does best in abundant sunshine, although both tuber formation and flowering are promoted by short
day lengths. A well-distributed rainfall of 750–1,000 mm per annum is best for the crop. Drought is particularly harmful to the crop during the first six weeks after planting and at the time of tuber initiation. Moisture in the form of rainfall or irrigation water must be available during the dry (non-cropping) season in order to permit the maintenance of plants whose vines will be used as planting material in the following season.

The best soil for sweet potatoes is sandy loam. Poorly drained, poorly aerated or saline soils tend to retard tuber development. Growth is best at a pH of about 6; alkaline soils result in poor yields.

**Botanical Description**

The sweet potato is a dicotyledonous herbaceous plant with a creeping growth habit. The plant is naturally perennial, but in agriculture it is usually planted and harvested within the same cropping year. When propagated by vine (stem) cuttings, the growth of the plant is marked by elaborate root growth during the first two months, extensive shoot enlargement in the third and fourth months, and vigorous tuber bulking for the rest of the season.

Sweet potato plants growing from vine cuttings develop a fibrous root system which penetrates deep into the soil. Roots also form at the various nodes where the stem is in contact with the soil. As early as the second month after planting, a few roots in the fibrous root system begin to enlarge and differentiate into tubers. These roots are mostly located within the top 25 cm of the soil. Their enlargement is due to the activity of the cambium which produces a large mass of storage tissue. Tuber formation is promoted by short-day conditions. It is inhibited by exposing the roots to light and by poor soil aeration.

A sweet potato plant produces several tubers (Fig. 50). Each tuber is attached to the stem base by means of a stout stalk. Tubers may be spherical, cylindrical or oval in shape and may attain weights of over 1 kg. The skin of the tuber may be whitish, brownish, yellowish or purplish, while the tuber flesh may be creamy-white, yellowish or purplish. Latex ducts are present in all parts of the tuber, so that a white sticky latex oozes out when the tuber is cut. The tuber characteristics used to distinguish various cultivars include shape, colour of skin, colour of flesh and texture after cooking. On the basis of texture after cooking, there are generally three groups of cultivars: those that are dry, firm and mealy; those that are soft, moist and gelatinous; and those that are coarse.

The stem of the sweet potato plant is thin, cylindrical, herbaceous and creeping. Younger stem portions are hairy but the more mature parts are devoid of hairs. The stem has the ability to produce roots
readily when placed in a moist medium. The leaves are simple and arranged spirally on the stem. The petiole is relatively long. The lamina is usually digitate, and may be green or purplish in colour.

Flowers are borne on cymose inflorescences or solitarily. There are five united sepals and five purplish petals which are united together to form a funnel-shaped structure. There are five stamens which arise from the base of the petals. The anthers are borne at various heights with respect to the stigma. The ovary has two locules each containing two ovules. Flowering is promoted by short-day conditions. Each flower is open for less than 12 hours before it wilts and dies. Moreover, there are various mechanisms such as self-incompatibility and heterostyly which tend to discourage self-pollination and encourage out-crossing.

The fruit is a capsule 5–8 mm in diameter. The seed is small (about 3 mm long) and black. It is flattened on one side and convex on the other. The testa is hard and impervious, so that scarification is often required for the seeds to germinate.

Cultivation

Cropping systems
Various rotations that include sweet potatoes are in use in Africa. In Sierra Leone and Zanzibar they are grown just before rice. In other cases, they are intercropped with maize, beans, cassava or yams.
Where the rainy season is long enough, two crops of sweet potatoes can be grown in a season, but for most locations only one crop is possible (Fig. 51).

Land preparation
Land preparation for planting sweet potatoes is similar to that for planting cassava or yams. Mounds, ridges and planting on the flat are all commonplace. Plantings on the flat yield lower than the others and are more difficult to harvest. Planting on the flat is also particularly unsuitable for soils with a high water table. Because ridge-making can be mechanized, it is progressively replacing mound-making as the most common land preparation for sweet potatoes.

Planting
The best planting material for sweet potatoes is the tip, the top 30 cm or so of the vine. Other parts of the vine may also be used if there is a shortage of tip portions. Pieces of the tuber or small intact tubers may sometimes be used for the commercial propagation of sweet potatoes, but this practice results in low yields, and utilizes tuber material which could otherwise have been used for food. Moreover, tuber material, unlike vine material, is able to transmit soil-borne diseases to the new crop.

The problem of having enough vine material available at the
beginning of the growing season is not an easy one for the farmer to solve. There are three approaches to this problem. The first is to maintain a small plot of sweet potatoes in a well-watered location all through the dry or non-growing season. Vines are then readily available when field planting is to be done. The second approach is to store the tubers for some time. A few weeks before the start of the growing season, the tubers are buried in moist soil. Sprouts arising from the tubers are removed at intervals and planted on the field. This practice is most prevalent where the non-growing season is either too long or too severe for the vines to survive. Each of the two foregoing methods of producing sprouts can be supplemented by the third approach, i.e. by taking vines from the earliest-planted portions of the field to plant later parts. In this case, of course, the crop on the field comprises plants of different ages which will be harvested at different times.

The planting operation involves the insertion of the basal portion of the vine into the soil. Insertion is such that the vines are nearly horizontal, so that the basal extremity of the vine does not lie very deep in the soil. If it lies very deep, tuber yield may be reduced. Insertion is also such that a half to two-thirds of the length of the vine lies beneath the soil. The planting operation is performed manually in most of Africa. Mechanical transplanter are in use in many developed countries.

Sweet potatoes are normally planted at a within-row spacing of 25–30 cm on ridges or rows that are 60–75 cm apart. Usually one vine is planted on each spot, but when mounds are used, two or three vines may be planted on various portions of the same mound. Where sweet potatoes are intercropped, the spacing between the plants will depend on the number and density of the other crops. It is best to plant sweet potatoes early in the rainy season so that the crop can make adequate growth and mature before the onset of the dry season.

**Fertilization**

Even though sweet potatoes may give reasonable yields on relatively poor soils, the crop usually responds well to fertilizer application. At the level of the traditional farmer, farmyard manure or compost may be used. For chemical fertilizers, a 6:9:15 NPK fertilizer applied at 560–1120 kg/ha may be generally recommended. The exact type and dosage of fertilizer used will depend on the nature of the soil, but excessive nitrogen fertilizer should be avoided since it delays tuber formation and promotes shoot growth at the expense of tuber growth.

Fertilizer applied to sweet potatoes should normally be split into
two doses. The first dose is applied immediately after planting, either dissolved in water and sprinkled on the plants, or as a band or spot application beside the plant. The second dose is applied at five or six weeks after planting.

Weed control
Sweet potato vines grown rapidly and compete effectively with weeds. For this reason, weed control measures are only necessary for the first two months after planting. Thereafter the crop, if planted at the correct spacing, covers the ground effectively and smothers most weeds. In traditional practice, weed control with hand tools is done about four weeks after planting. Herbicidal weed control in sweet potato plots is not widespread in Africa, although it is common practice in some other parts of the world. Herbicides that have been found effective include diphnamid and Amiben (chloramben), each at about 3.5 kg/ha.

Harvesting
Most sweet potato cultivars are mature for harvest five months after planting. Harvesting too early results in low yields, while an unduly delayed harvest may cause the tubers to become fibrous. Delaying the harvest for too long also encourages the build-up of the sweet potato weevil which attacks the tubers. Where sweet potatoes are grown for subsistence, the crop is sometimes harvested as needed by the household, rather than harvesting the entire field at one time.

In most parts of Africa, sweet potatoes are harvested manually by means of sharpened sticks, metal rods or machetes. Care should be taken to avoid tuber wounding during the harvesting operation. Mechanical harvesters for sweet potatoes are in use in various parts of the world. Such machines first remove the vines and then dig out the tubers. The tubers are then sorted and loaded on trucks. In some instances, only the vine clearing and digging of the tubers are done mechanically; the sorting and loading are done by hand.

Yields
Sweet potato yields in Africa average approximately 5 tonnes/ha. These are rather low yields compared with average yields of 16 tonnes/ha in Asia and 10 tonnes/ha in South America. The main reasons for these low yields in Africa are poor crop management and the use of low-yielding cultivars. With better management and the introduction of high-yielding cultivars the average yields are expected to increase substantially. In some restricted locations and at experimental stations, yields as high as 20 tonnes/ha are already being regularly obtained.
Storage
After harvest but before storage, the tubers are subjected to curing, a process which promotes the healing of wounds inflicted during harvesting, and toughens the tuber skin. Curing is best done by subjecting the freshly harvested tubers to a temperature of 27–29.5°C and a relative humidity of 85–90% for 4–7 days. This is usually done in a well-ventilated storehouse. In many parts of the tropics, the normal environmental conditions are very close to those required for curing, so that curing is accomplished by simply leaving the tubers exposed to ambient conditions for a few days before they are packed for storage.

After curing, the best conditions for storing sweet potatoes are a temperature of 13–16°C and a relative humidity of 85–90%. For most parts of the tropics, including tropical Africa, the attainment of such temperatures requires refrigeration which may not always be available or economical. Most producers in Africa simply store their sweet potatoes under ambient conditions in baskets, in underground pits, or on platforms. Since temperatures under such conditions are relatively high (above 16°C), the tubers tend to become pithy due to the development of intercellular air spaces within the tuber flesh. Moreover, tuber respiration is high and sprouting occurs readily. For all these reasons, the tubers tend to deteriorate after only one or two months of storage. For more prolonged storage of sweet potatoes in the tropics, the lowering of temperatures with refrigeration is essential.

Crop Protection
Diseases
Black rot is caused by the fungus Ceratocystis fimbriata. The disease has been reported in West Africa and in other parts of the world as well. It may attack the plant in the field, or the tuber during storage. It causes a blackening of the tuber and underground stem portions. Infected tubers produce some toxins which cannot be removed by boiling. The disease is controlled by:

* the use of resistant varieties
* establishing the crop with vine cuttings rather than tuber pieces or sprouts pulled directly from tubers. In this way, the farmer can ensure disease-free planting material.
* crop rotation in which the field is kept free of sweet potatoes for three or four years
* washing the tubers with borax or another fungicide before storage.
Mosaic is a virus disease which is becoming increasingly serious in sweet potatoes in Africa. The causal organism is a strain of the tobacco mosaic virus. Symptoms of the disease include small, malformed leaves and a considerably reduced yield of tuber. The disease does not spread rapidly from plant to plant, so that the removal and burning of infected plants is an effective control measure.

**Insect pests**

_Sweet potato weevils_ (Cylas spp.) are one of the most serious pests of sweet potatoes. They occur in most areas where the crop is grown, in Africa and in the rest of the world. The female lays eggs in small pockets which it makes at the base of the stem and in the tuber. Each egg is protected with a plug of faeces. In the tropics, the eggs hatch in about 8 days. The resulting larvae then tunnel extensively through the tuber, feeding on it and depositing frass within it. This also promotes the rotting of the tuber. After feeding for some time, the larva pupates. The black adult weevil emerges after 15–20 days of pupation. Apparently the deeper the tuber is located in the soil, the less likely it is that it will be attacked by the weevil. Several control measures can be adopted:

* the use of resistant cultivars
* the use of insecticides such as 0.1% carbaryl applied three times at three-week intervals, starting at the time of tuber formation. The use of 0.1% fenthion, 0.1% fenitrothion or 1% heptachlor have also been recommended.
* harvesting as soon as the tubers are mature, as delayed harvesting promotes weevil infestation.
* effective quarantine to prevent the spread of the weevil in transported plant material. This is important and efficacious because the weevil itself cannot fly over long distances.
* crop rotation with non-susceptible crops, accompanied by the eradication of all infested sweet potato residues at the end of the season.
* planting weevil-free material, as well as earthing up to ensure that the tubers are deep within the soil.

_Hawk moths_ (Herse convulvuli) are a serious pest of sweet potatoes in Africa. The moth lays its eggs in soil, and the larvae feed extensively on sweet potato leaves. Control is by spraying with suitable insecticides.
COCOYAMS
(TARO AND TANNIA)

Origin and Distribution
In many parts of Africa, the term 'cocoysams' is used to refer collectively to members of the genus Colocasia and the genus Xanthosoma which are used for food. When referred to separately, Colocasia species are called 'taro' while Xanthosoma species are called 'tannia'. Of course, other common names exist for these crops in various parts of the world.

Taro is referred to botanically as Colocasia esculenta (L.) Schott. The cultivars of taro fall into two groups:

* those with small corms and large cormels. This is sometimes called the 'eddeo' type and some scientists consider it to be a separate botanical variety, namely Colocasia esculenta var. antiquorum.

* those with large corms and small cormels, sometimes called the 'dasheen' type, or Colocasia esculenta var. esculenta.

Taro originated in south central Asia and was first cultivated in that region. From there it first spread to the Pacific Islands and later to the Mediterranean area and West Africa. From West Africa it was introduced to the West Indies. Today it is grown in nearly all parts of the humid tropics.

Tannia consists of several species of Xanthosoma, with X. sagittifolium being the most important. It originated in Central and South America and was first cultivated there. From there it spread to South-East Asia and the Pacific Islands. It was introduced to Africa in the nineteenth century, much later than taro. Partly for this reason the local name for tannia in many communities is an adjectival qualification of the name for taro. For example, tare may be called 'cocoym' while tannia is called 'new cocoym'.

Today, more that three-quarters of world cocoym production comes from Africa (Table 16). The rest comes from Asia and Oceania. Nigeria, Ghana and Japan are the world's leading producers. In Africa, there is probably a greater production of tannia than of taro, but in Oceania and Japan, taro is more important than tannia.

Utilization
The fresh cocoym corm is composed of 70–80% water, 20–25% starch and 1.5–3% protein. It also contains significant amounts of vitamin C, thiamin, riboflavin, niacin and carotene. The starch
grains of taro are small in size and are more easily digested than those of yam, cassava or sweet potato. The protein content of taro and tannia is also higher than that of these other tropical tuber crops. Fresh cocoyams contain substances (calcium oxalate crystals) which are irritating to the skin and mouth. The irritating effect is removed when the corm or cormel is cooked.

The corms and cormels of cocoyams are eaten in the same way as yams or sweet potatoes, i.e. boiled, fried, baked or roasted. In West Africa, the boiled cocoyam is sometimes pounded to produce a paste similar to pounded yam, and eaten in the same way. The corms and cormels of taro are equally used for food, but for tannia in Africa, only the cormels are normally used for food. The corms tend to be woody and are reserved as planting material or livestock feed.

Cocoyam flour is one of the few processed forms of cocoyam encountered in Africa. This is made by peeling and slicing fresh or cooked corms and cormels, drying the slices, and milling the dried slices into flour. Poi is a processed form of taro which is popular in Hawaii but is unknown in tropical Africa. It is made by cooking, mashing and straining the taro corms. The strained product is then placed in bags where a slight fermentation occurs before it is eaten.

Cocoyam leaves are used for human food in various parts of the world, including several countries in tropical Africa. The leaves are very nutritious since they contain up to 20% protein on a dry weight basis, in addition to appreciable amounts of vitamins and minerals. Like the corm and the cormel, the leaf is irritating if eaten raw and must therefore be boiled before consumption.

The corms, cormels and leaves of cocoyams can be used as animal feed. In areas where the leaves are still green at harvest, there is a great potential for utilizing the leaves left after harvest for feeding
animals. In order to minimize irritation to the animals and to improve palatability, it is advisable to turn the leaves into silage before feeding them to the animals.

There is some export trade in cocoyams from the South Pacific islands to New Zealand, and from the West Indies to Western Europe, but the quantities involved are rather small. In Africa, there is very little international trade in cocoyams.

**Adaptation**

Cocoyams have a high moisture requirement and grow best where 2,000 mm or more of water can be provided each year through rainfall or irrigation. Moisture stress during the season results in mis-shapen corms of poor quality. Cocoyams are a warm-weather crop and do best when temperatures are above 21°C. They perform poorly if temperatures are low. It appears that cocoyams are able to tolerate shady conditions better than most other crops.

Taro is able to tolerate waterlogged conditions, but for tannia, a well-drained soil is essential. Cocoyams prefer a soil pH of 5.5–6.5 and are able to tolerate saline soils.

**Botanical Description**

Cocoyams are herbaceous plants. Each plant has a more or less spherical corm which lies just beneath the soil. The apex of the corm is the main growing point of the shoot. This growing point lies close to the soil level. Leaves arise from the upper part of the corm, while the fibrous roots extend from practically all parts of the corm. Cormels and daughter corms (suckers) arise laterally from the main corm. Tannia is generally a larger and more vigorous plant than taro (Fig. 52).

Each corm is a perennating structure, densely packed with starch. Leaf scars are prominent on it, and numerous axillary buds (‘eyes’) are present on the body of the corm. Cormels which arise laterally from the corm are in fact stem tubers. They have a terminal bud at their distal end, scale leaves on their surface, and numerous buds in the axils of the scale leaves. Cormels are usually cylindrical or flask-shaped, and each corm may bear numerous cormels at different ages (Fig. 53). For taro, both corms and cormels are used for food, but for tannia, preference is given to cormels for consumption. As has already been mentioned, cocoyam cultivars differ in the relative ratios of corm and cormel that they produce.

The aerial portion of cocoyams consists mainly of the leaves. Each leaf is attached to the corm by means of a long petiole which is flared out at the end where it attaches to the corm. Large air spaces exist in the petiole and in the major veins of the lamina, so that the petiole
and veins have a rather spongy texture. The shape and venation of
the lamina, and the mode of attachment of the petiole to it, are major
distinguishing features between taro and tannia. The leaf of tannia is
distinctly heart-shaped, with a deep indentation which divides the
base of the lamina into two lobes. The petiole is attached at the
junction of the margins of these two lobes. From the point of attach-
ment of the lamina, a thick mid-rib runs to the apex of the leaf, while
two large veins run to the basal lobes. There is also a prominent vein
which runs along the margin of the leaf. Otherwise, the general
venation is reticulate.

Fig. 52 Tannia
For tarc, the leaf is more circular in shape and the basal lamina lobes are less sharply demarcated than for tannia. Moreover, the attachment of the petiole is somewhere in the middle of the lamina (i.e. peltate attachment) and not at the margin where the two lobes meet. Several main veins radiate from the point of attachment of the petiole, but as with tannia, the general venation is reticulate.

Natural flowering in cocoyams is relatively rare. The inflorescence is a spadix, and each plant may produce several inflorescences one after the other. Each inflorescence consists of a stout peduncle, a large yellowish bract called the spathe, and the spadix which consists of a central axis to which numerous small flowers are attached. The spathe partially ensheaths the basal portion of the spadix. The flowers on the spadix are unisexual, the female flowers occurring at the basal (proximal) portion of the spadix, and the male
flowers occurring at the distal part. Some sterile flowers occur between the regions of female and male flowers. In taro, but not in tannia, the extreme distal part of the spadix has no flowers at all.

Each female flower consists of an ovary with a sessile stigma, while each male flower consists of 2–6 stamens which are fused together. The flowers are scented and pollination is probably by insects. The fruit is a berry. The seed has a hard testa, contains endosperm in addition to the embryo, and germinates with difficulty.

Although natural flowering is rare in cocoyams, flowering occurs readily when the plants are treated with gibberellic acid. This substance is now being used by cocoyam breeders to cause frequent flowering so that desired hybridizations can take place.

**Growth cycle**
The period immediately after planting is marked by rapid shoot growth. The leaf area continues to increase until about six months after planting and then declines. All through the season there is a rapid turnover of leaves, with new ones appearing as older ones die. Corm formation starts about three months after planting but the major period for corm bulking is from the fifth or sixth month onwards. As the plant matures, the leaves begin to yellow, and when the growing season is over, the shoot dies back completely, leaving only the underground portions. If the plant is left unharvested, the corms and correls will sprout and give rise to new plants when favourable conditions return. If favourable growing conditions exist throughout the year, the shoot may fail to die back and the plant will continue to grow indefinitely.

**Cultivation**

**Cropping systems**
The ability of taro to grow and yield well under flooded conditions has led to the adoption of flooded culture for the crop in some parts of the world. This development has taken place mainly in Hawaii. The crop is planted into standing water, and the field is kept flooded throughout the life of the crop. Taro grown in this way yields higher than that grown in unflooded conditions, although it takes longer to mature. In this system the farmer practises monoculture, so that taro is grown on the land for several seasons before the field is dried and another crop grown. In some parts of the world, taro is grown on land that is naturally swampy or poorly drained, thus permitting economic utilization of land which would otherwise be useless. Similarly, cocoyams have been used to reclaim saline soils on which very few other crops would grow (Warid, 1971).
Tannia cannot tolerate waterlogging and is therefore always grown without flooding. In most parts of the world, including Africa, taro too is grown without flooding.

Cocoyams resemble yams and cassava in being shallow-rooted and in having a high requirement for potassium. For this reason, cocoyams do poorly if grown after yams or cassava. When cocoyams are part of an intercropping mixture, use is often made of their shade-tolerating capabilities. For this reason they can be grown between stands of plantation tree crops such as coconut or oil palms as they are able to utilize the low light intensities filtering through the canopy of the tree crop. Similarly, when cocoyams are intercropped with staked yams in many parts of West Africa, the yams form an upper canopy layer beneath which the cocoyams grow in relative shade.

Another interesting cropping system involving cocoyams is where they are used as nurse crops to provide shade for tender seedlings of cocoa or coffee in West Africa. Because of its broader leaves and larger plant size, tannia is more often used for this purpose than taro.

Land preparation

For the cultivation of tannia, and the non-flooded cultivation of taro, the land is prepared in the same way as for the other tuber crops already discussed. Planting on the flat, ridges, or mounds are the common practices. Harvesting is easier on ridges and mounds than on the flat.

For the flooded cultivation of taro, elaborate land preparation may be required to obtain a field that is relatively level. Dykes have to be built around the field so that water can be impounded. Land preparation in these circumstances may be carried out while the field is wet; sometimes the field is deliberately puddled to aid water retention (Fig. 54).

Planting material

Because of the profusion of buds on the corm and cormel, cocoyams can be conveniently established from intact corms, intact cormels, or pieces of corms and cormels. The best planting material is a piece consisting of the apical portion of the corm with the lower 20 cm or so of the petioles still attached. Such a planting piece is called a 'huli' in Hawaii, where it is the major type of planting material. It is preferred to the other kinds of planting material because it establishes more quickly and yields higher than the other kinds. Moreover, the small portion of the corm which it usually contains is of little value for food. Huli are normally obtained by chopping off the top portions of ware corms at harvest. A similar kind of planting
material can be obtained at harvest by uprooting small daughter corms (suckers) and using them, with their attached leaves, as planting material. In the South Pacific Islands such as Fiji, suckers are the main type of planting material.

When the unfavourable season is short and planting occurs shortly after harvest, huli and suckers provide the ideal planting material. If, however, there is a period of two or three months between harvest and planting, the farmer is faced with considerable difficulty in producing adequate planting material, because huli and uprooted suckers cannot be stored for long. This is the situation in many cocoyam-growing parts of Africa. There are several possible options open to such farmers. They can:

* establish a nursery in a well-watered location, utilizing the huli and suckers obtained at harvest. The huli or suckers are planted at very close spacing, and are transplanted to the field when the favourable season returns.
* establish a similar nursery using pieces from stored corms, cormels and suckers. In this case the nursery is established and maintained for only about six weeks prior to the anticipated time of planting in the field.
* leave the suckers on the field at the time of harvest. They will die back during the dry season, but will sprout again when the rains begin. The farmer can then transplant directly from the old field.
to the new one. This practice, however, entails that the new field is established late, since the farmer must wait for the suckers to sprout on the old field.

* plant the field directly with pieces derived from stored corms and cormels. Such a crop usually establishes rather slowly, and yields are rarely high.

_Crop establishment_

Cocoyams are best planted at the onset of the rains, so that they have the entire rainy season to make their growth. Where irrigation or rainfall is available year-round, the crop can be planted at any time of the year, as is the case in Hawaii. In subtropical countries such as Egypt, planting should be done in spring so that the crop grows during the summer months.

A spacing of 60 × 60 cm has been recommended for cocoyams. In most of tropical Africa today, cocoyams are spaced too wide apart. The crop canopy therefore does not close early enough and weeds are a problem, resulting in relatively low yields. These yields could be improved by adopting a more appropriate spacing. As a rule, closer spacing increases corm yield per hectare but decreases corm yield per plant. Where cocoyams are grown as part of an intercropping mixture, their spacing will vary depending on the nature and density of the other crops.

Cocoyam planting pieces should be planted to a depth of about 7 cm in the soil. If hull or suckers are used, the base of the material should lie about 7 cm beneath the soil, while the petiole bases lie above the soil. Deep planting is essential to encourage the plant to root deeper and to ensure that the new corm produced is not partially exposed above the soil. Partly mechanized cocoyam planters are available in various parts of the world. These operate essentially by opening up a deep furrow, having the planting pieces inserted, and then closing up the furrow.

For the flooded cultivation of taro, the crop is planted into 2–5 cm of standing water. The planting piece is inserted by hand into the loose puddled soil. As the base of the plant continues to grow upwards, the water level is raised in stages so that the plant's base remains continually submerged. The water on the field is regularly replenished with fresh water in order to avoid the build-up of root rots.

_Fertilization_

Cocoyams have a high requirement for potassium and calcium. The crop also responds well to nitrogen fertilizer, but excess nitrogen tends to depress yields. The exact quantities and kinds of fertilizer
depend on the soil type. In Puerto Rico, for example, the recommended fertilizer rates for tannia are 112 kg/ha nitrogen, 45 kg/ha phosphorus and 112 kg/ha potassium. Generally, more fertilizer is required for flooded taro than for non-flooded taro or tannia.

Because cocoyams grow in a high moisture regime, fertilizers applied to them are subject to leaching and should therefore be applied in split doses. The first application is made at planting, and the second is made three or four months after planting, just as corm enlargement is commencing. In flooded taro culture, the field may occasionally be drained to permit fertilizer application. However, reflooding of the field should occur within a few days of fertilizing.

Most cocoyam cultivation in tropical Africa takes place without chemical fertilizers. The farmers usually rely on the native fertility of the soil, although they may sometimes supplement it by placing compost or farmyard manure in the planting holes.

Weed control
Weeds are a problem in cocoyams during the early part of the season when the leaf area is building up, and during the last two or three months when the leaf area is declining. For dry-land (non-flooded) taro and tannia, hand tools are the most common method of weed control. Weeding should be as shallow as possible to avoid damaging the shallow root system. Various herbicides have proved effective in weed control in cocoyams. TCA (5 kg/ha) used with diuron (3 kg/ha) or atrazine (3 kg/ha) can be used for dry-land taro or tannia. A pre-emergence application of prometryne (1.2 kg/ha) can also control weeds for the first one or two months after planting. In Japan, a layer of black polyethylene mulch has been found effective for weed control in dry-land taro.

For flooded taro, the very practice of flooding serves as a weed control measure as only a few weed species are able to survive the flooded conditions. Where necessary, herbicides can be introduced in the irrigation water. Nitrofen at 3–6 kg/ha has been used in this way in Hawaii. Alternatively, the land can be drained temporarily and any of the herbicides recommended for dry-land taro can be used.

Harvesting
Cocoyams are ready for harvest after 7–11 months. The leaves may begin to turn yellow at this time, but if growing conditions are still favourable, appreciable yellowing may fail to occur, and there may be no morphological changes to indicate maturity. However, there is little or no deterioration if the crop is left in the ground for a few
weeks after maturity. In a few localities in Africa, multiple harvesting is practised for tannia. In that case, only the cormels are removed at each harvest, while the corm is left to produce new generations of cormels which will be harvested later.

Most cocoyams grown in Africa are harvested by hand or with hand tools. If the conditions are dry at harvest time, the roots are usually dead, so that the crop can be lifted by pulling the withered aerial parts. Alternatively the crop may be ploughed out, after which the corms and cormels are picked manually. For flooded taro, or in situations where dry-land taro and tannia are harvested when a favourable growing season still exists, the roots are alive at harvest and some digging instrument is required to extract the corm and cormels from the soil. In all cases care should be taken to avoid wounding the corms and cormels during harvest. Mechanical harvesters for cocoyams are not common at present, but efforts are being made at various centres to develop efficient ones.

**Yields**

Yields of cocoyams in the world average about 5 tonnes/ha. The highest yields of 37–75 tonnes/ha are recorded for flooded taro in Hawaii. Dry-land taro in Hawaii yields 15–25 tonnes/ha. In Africa, yields of taro vary from country to country. Egypt, with 31 tonnes/ha, has some of the highest yields. In Nigeria and Ghana, yields average 5 tonnes/ha. Tannia yields of 25–37 tonnes/ha have been reported in Puerto Rico, but average yields there are about 12–20 tonnes/ha.

**Storage**

For prolonged storage, cocoyams should be kept at about 7°C at a relative humidity of 85%. Under these conditions, cocoyams can store well for up to four months. If the temperature is much higher, respiration, rotting and sprouting cause storage life to be shortened; if the temperature is much lower, the buds die and the corms decay. Traditional storage practices include storage in underground pits, as is done for tannia in Cameroon, or storage on open platforms. Even with these methods, the crop can keep satisfactorily for only a few weeks. Many farmers simply avoid having to store cocoyams by leaving the crop in the field and harvesting only as needed.

**Crop Protection**

**Diseases**

*Taro leafblight* is caused by the fungus *Phytophthora colocasiae*. The disease appears on taro leaves as water-soaked lesions which later spread to cause necrosis of most of the leaf (Fig. 55). The disease is favoured by hot, humid conditions. It is controlled by the
use of copper-based fungicides such as copper oxychloride and tribasic copper sulphate. The use of resistant varieties is also recommended, although there are not many such varieties available at present. The disease does not attack tannia.

**Soft rot.** caused by several species of *Pythium*, attacks both taro and tannia. The pathogen exists in the soil and attacks the roots, corms and cormels, causing them to rot. The leaves also yellow and wilt. The disease is controlled by the use of resistant varieties, by planting disease-free material and by crop rotation. Treating the soil and planting material with captan fungicide has sometimes proved effective.

**Nematodes**

**Root-knot nematodes** (*Meloidogyne* spp.) cause galls and irregular swellings on the underground portions of cocoyams, resulting in
stunting of the plant. Control is by planting nematode-free material. Planting material that is already infested should be treated with water at 40°C for 50 minutes. Infested soil should be fumigated with a nematicide such as Nemagon or Hexanema.
12
GRAIN LEGUMES

NUTRITIONAL IMPORTANCE
The frequently quoted axiom “man does not live by bread alone” is a biological fact. To prevent malnutrition, a diet must provide both sufficient calories and the correct nutritional balance. In most developing countries, the average diet is high in starch and low in protein. All cereals, roots and tubers are rich in starch but poor in protein.

Cereals are an excellent source of energy (starch) but a comparatively poor source of protein, whereas several genera in the family Leguminosae provide large amounts of high-quality protein. The protein of grain legumes contains relatively high amounts of the essential amino acids lysine and tryptophan, and thus usefully complements the protein supplied by cereals, in which the contents of lysine and tryptophan are relatively low. On the other hand, the protein of grain legumes contains relatively low amounts of the sulphur-containing amino acids methionine and cystine, which are present in relatively high amounts in the protein of cereals.

Proteins from both field beans and soybeans are nutritionally complete when supplemented with methionine. Soybean meal contains about 40% protein (comparable to some sources of animal protein and far less expensive). Groundnuts are also an exceptionally good source of high-quality protein. Grain legumes are also useful sources of thiamine (Vitamin B₁), niacin (Vitamin B₃) and calcium.

The protein requirements of man can therefore be fully satisfied with a balanced cereal-legume diet, or with a legume diet supplemented with specific amino acids. The combination of soybeans and rice, wheat and gram, or maize and beans provides adequate, well-balanced nutrition.

Legumes cultivated especially for their mature seeds for human consumption are called pulses or grain legumes, but their immature seeds and the young pods and leaves are also eaten as vegetables. The vegetative parts of grain legumes are commonly fed to livestock.
after their seeds have been harvested; species which are cultivated only to feed livestock are called fodder or forage legumes, or if they are grown in mixtures with pasture grasses, pasture legumes. Another group of legumes, the cover crops, is grown in the tropics to smother weeds, to restrict soil erosion and to enrich soil nitrogen. They are often grown to cover the ground in plantations of trees such as rubber and cocoa.

Although early man knew nothing of protein balance and amino acid requirements, surely more than blind luck brought cereals and legumes into his diet. By trial and error he must have realized that some combinations of plants were better for him than others. The special value of legumes as food has always been appreciated, but it has recently been emphasized as a result of increasing world population and the awareness of our need to produce more food, especially more protein.

HISTORY OF LEGUME CULTURE
The cultivation of legumes is almost as old as that of cereals. Archaeological evidence shows that legumes were cultivated before 5,000 BC. The earliest written record of the culture of soybeans – perhaps the oldest cultivated legume – dates back to 3,000 BC in China. There is also evidence that some legumes were cultivated in Central and South America from four to six thousand years ago. Soybeans, which are becoming an increasingly important world-wide source of high-quality protein, are the most important edible legume produced today. Groundnuts are another major edible legume of the world.

Besides soybeans and groundnuts, the following are the important legumes. Lentils (Lens esculenta), which originated in South-West Asia and have been an important food throughout history, continue to be of significance in Asia and, to a lesser extent, in parts of Europe. Cowpeas (Vigna unguiculata) are grown in tropical Africa. Various species of the genera Phaseolus, Vicia and Cicer are important legumes of Asia, Africa and Europe. Both the black gram or urd (Vigna mungo), and green gram or mung (Vigna radiata) are grown extensively in India. The broad bean (Vicia faba) is well adapted to northern Africa. India is the major producer of chickpeas (Cicer arietinum), also called garbanze or gram. These are also grown in the USA, Mexico, Spain and Turkey.

A wide variety of grain legumes are found in the tropics, but only the important ones grown in tropical Africa are described in this chapter. They are grown mainly for their mature seeds for human consumption. Soybeans and groundnuts, though very important
grain legumes, are also well known as oil-seed crops, hence they are described in the next chapter, on oil-seed crops.

**Phaseolus and Vigna Species**

Both *Phaseolus* and *Vigna* belong to the tribe Phaseoleae of the subfamily Papilionoideae of the family Leguminosae. The genus *Phaseolus* differs from *Vigna* in that its stipules do not have appendages below their point of attachment to the stem; its pollen grains are smooth, not with an open reticulation of raised walls; and all its species have coiled keels whereas most *Vigna* species do not.

The best known and most widespread of the *Phaseolus* species is *P. vulgaris*, the common bean. Similarly, of the *Vigna* species, *V. unguiculata*, the cowpea, is the most important bean grown in Africa. In this book only these two have been described under beans and cowpeas. The nutritional values of the grain legumes described in this book are given in Table 17.

<table>
<thead>
<tr>
<th>Crops</th>
<th>Nutritional values (%)</th>
<th>Carbohydrate</th>
<th>Protein</th>
<th>Fat (oil)</th>
<th>Fibre</th>
<th>Ash</th>
<th>Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groundnuts (shelled)</td>
<td>11.7</td>
<td>30.4</td>
<td>47.7</td>
<td>2.5</td>
<td>2.3</td>
<td>5.4</td>
<td></td>
</tr>
<tr>
<td>Soybeans</td>
<td>25.0</td>
<td>39.0</td>
<td>13.0</td>
<td>3.1</td>
<td>4.8</td>
<td>10.1</td>
<td></td>
</tr>
<tr>
<td>Cowpeas (dried)</td>
<td>56.8</td>
<td>23.4</td>
<td>1.3</td>
<td>3.9</td>
<td>3.6</td>
<td>11.0</td>
<td></td>
</tr>
<tr>
<td>(green)</td>
<td>7.4</td>
<td>3.4</td>
<td>0.3</td>
<td>1.8</td>
<td>0.9</td>
<td>86.2</td>
<td></td>
</tr>
<tr>
<td>Common beans (dried)</td>
<td>57.8</td>
<td>22.0</td>
<td>1.6</td>
<td>4.0</td>
<td>3.6</td>
<td>11.0</td>
<td></td>
</tr>
<tr>
<td>(green)</td>
<td>6.3</td>
<td>6.1</td>
<td>0.2</td>
<td>1.4</td>
<td>0.8</td>
<td>85.2</td>
<td></td>
</tr>
<tr>
<td>Pigeon peas (dried)</td>
<td>57.3</td>
<td>19.2</td>
<td>7.5</td>
<td>8.1</td>
<td>3.8</td>
<td>10.1</td>
<td></td>
</tr>
<tr>
<td>Field peas (dried)</td>
<td>58.5</td>
<td>22.5</td>
<td>1.0</td>
<td>4.4</td>
<td>3.0</td>
<td>10.6</td>
<td></td>
</tr>
<tr>
<td>(green)</td>
<td>15.5</td>
<td>6.7</td>
<td>0.4</td>
<td>2.2</td>
<td>0.9</td>
<td>74.3</td>
<td></td>
</tr>
<tr>
<td>Chickpeas (dried)</td>
<td>61.2</td>
<td>17.1</td>
<td>5.3</td>
<td>3.9</td>
<td>2.7</td>
<td>9.8</td>
<td></td>
</tr>
</tbody>
</table>
COWPEAS
(Vigna unguiculata (L.) Walp)

Out of 170 species in the genus Vigna, three, namely cowpea (V. unguiculata) green gram (V. radiata) and black gram (V. mungo) are important grain legumes of the world. There are three subspecies in the species unguiculata. They are unguiculata (cowpea), cylindrica (cat-jang) and sesquipedalis (yard-long, asparagus bean). Cowpeas, when grown for their dry seeds, are also known as black-eyed peas, black-eyed beans, China peas and marble peas. Cultivars grown for their long immature pods are variously known as yard-long beans, asparagus beans, bodi beans and snake beans.

Origin and Distribution
Besides the three cultivated subspecies noted above, one wild subspecies, dekindiana, occurs in Africa. This is the wild ancestor of the cultivars which were domesticated in the Ethiopian region, or in West Africa, or perhaps widely throughout the African savanna zone, more than 4,000 years ago. The earliest cultivars in Africa were probably spreading, photosensitive, short-day types of the subspecies unguiculata. This subspecies probably reached India with sorghum and bulrush millet from East Africa around 1,500 BC. In India, the two other cultivated subspecies, cylindrica and sesquipedalis, were selected from it. These two Indian subspecies are rare in Africa as relatively recent introductions. Cowpeas reached southern Europe from Asia before 300 BC, and the New World in the seventeenth century from West Africa and Europe.

Area and Production
Cowpeas are the second most important food grain legume crop in tropical Africa, the most important being Phaseolus vulgaris, the common bean. Nigeria, Niger, Burkina Faso, Uganda and Senegal grow cowpeas for the 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 are grown extensively in South-East Asia and in Latin America, and to a limited extent in the southern part of the USA.

Utilization
Cowpeas are an important food for human beings; they also provide feed, forage, hay and silage for livestock, and green manure and
cover crops for maintaining the productivity of soils. The dried seeds may be ground into meal or flour which is used in a number of ways. The fresh seeds and immature pods are eaten as vegetables. They may be frozen or canned. The young shoots and leaves are eaten as spinach and provide one of the most widely used pot-herbs in tropical Africa. They are often dried and stored for dry-season use. The dry seeds are also fed to cattle. As a silage crop, cowpeas are commonly grown mixed with sorghum. Cowpea hay, when well cured, is considered to be of high nutritive value. Cowpeas are also grown for soil improvement as it is a good green manure crop. When intercropped with cereals, it compensates for the loss of nitrogen removed by cereals. It is also a good cover crop to restrict soil erosion.

Adaptation
Cowpeas are a warm-weather annual crop. They withstand heat better than most other legumes and are very drought-resistant. They are most important in the semi-arid tropics where they are grown mainly for their mature seed. Moisture deficiency has an adverse effect mainly on vegetative growth; seed formation is less affected. Cowpeas can be grown with less rainfall and under more adverse conditions than the common bean (P. vulgaris).

Cowpeas can be grown successfully on a great variety of soils, provided they are well drained. Light sandy loam soils are more suitable than heavy soils. Cowpeas can tolerate acidity under conditions of heavy rainfall. Sometimes they are grown on poor acid soils as a soil improver.

Botanical Description
Cowpeas can be erect, semi-erect, prostrate (trailing) or climbing annual herbaceous legumes. They have a deep tap root system with numerous spreading laterals in surface soils. The growth habit ranges from indeterminate to fairly determinate. The plant continues to blossom and produce seed for an extended period. The non-viny type tends to be more determinate in blooming habit and some improved cultivars blossom over a short period. In indeterminate cultivars, flowers and ripe pods are found together on the same plant.

The flowers are white or purple. Most cultivars produce medium (20 cm) to very long (50 cm or more) peduncles, each peduncle producing 2–4 or more pods. The pods are smooth, 15–25 cm long, cylindrical and somewhat curved. Each ped may have 8–20 seeds. The seeds are very variable in size, shape and colour (Fig. 56).
Indeed, pod and seed size are the chief distinguishing characteristics of the three cultivated subspecies, as follows:

* subspecies *unguiculata*: pods 10–30 cm long, pendant, seeds 5–12 mm long
* subspecies *cylindrica*: pods 7.5–13 mm long, usually erect, seeds 5–6 mm long
* subspecies *sesquipedalis*: pods longer than 30 cm, flabby, seeds usually 8–12 mm long.

**Cultivation**

*Cropping systems*

Cowpeas have a beneficial effect on subsequent crops in the rotation and also on the crops grown in association with them. Cowpeas are deep-rooted, and like other legumes, fix atmospheric nitrogen in the soils. In Africa, cowpeas are mostly grown in association with other crops, mainly with sorghum and millet. In the traditional cereal farming systems of West Africa, cowpeas are interplanted with sorghum or millet about 6 weeks after the cereals are sown, and after they have been weeded and earthed up. The spreading growth of the cowpeas soon smothers weeds, protecting the soil from the impact of heavy rainfall, and it is likely that the cereals derive some nitrogen from the root nodules of the cowpeas, especially towards the end of
the growing season. Their roots also excrete a substance that provokes the germination of the parasitic witchweed (Striga lutea). Cowpeas are therefore useful as a trap crop for this root parasite. They are a good preceding crop for cotton and cereals.

**Land preparation**

Land preparation depends on the cropping system, i.e., whether the crop is grown sole or interplanted with cereals or yams. When it is interplanted with cereals or yams, no additional land preparation is needed. When it is to grown as a sole crop then the seed bed for cowpeas should be firm, free of clods, and moist at the time of sowing.

**Sowing**

In order to obtain high seed quality, it is desirable that the sowing date should be such as to enable the crop to flower close to the end of the rains and for the seeds to mature in dry weather while there is stored moisture in the soil. Thus in different ecological zones of West Africa, cowpeas are sown at different times. In Nigeria, for example, cowpeas are sown during the first week of July in the Sudan zone, by mid-July in the northern Guinea zone, by the third to the fourth week of July in the northern half of the southern Guinea zone, as soon as the late season rain starts in the southern part of the southern Guinea savanna, and about mid-August in the derived savanna and forest zones.

For the quick and uniform emergence of seedlings, sowing
should be done in moist soil. Soil crusting produced by rains and
subsequent drying may cause poor seedling emergence and thin
stands. Thick sowing by using a high seed rate is a common practice
in Africa. This is to ensure a good plant stand. When the plants are
well established, thinning is done. The plants removed at thinning
are used as pot-herbs. Row planting is to be encouraged. The exist-
ing practice is to sow cowpeas at 30 cm space on ridges 90 cm apart.
For higher yields, closing spacing is recommended. The spacing of
rows should be adjusted to the type of cultivar, i.e. whether erect or
spreading. Row spacing will vary from 60–100 cm and plant spac-
ing from 10–30 cm. Erect cultivars will be sown at closer spacing
than the spreading ones. The recommended seed rate for the spread-
ing type is 10–15 kg/ha. For the erect type, the seed rate is about
double that of the spreading type.

On lanc being sown to cowpeas for the first time, particularly in
regions where the crop is not common, the seed should be inocu-
lated with a fresh culture of cowpea bacteria to ensure the desired
development of root nodules. Inoculation should be done just
before sowing.

**Fertilization**

If cowpeas are intercropped with other cereals or yams, the fertil-
ers applied to the main crop will meet the requirements of the
cowpeas. Also when they are sown following a fertilized cereal
within the same year (as is often the practice in southern Nigeria,
where the rainy season is long enough for two crops) further fertil-
ization is not necessary. When cowpeas are sown for the first time in
a field, or when the soil is very deficient in nitrogen, a starter dose of
nitrogen at 20 kg/ha may be necessary.

Cowpeas have a high requirement for phosphorus, in particular
towards the end of the growth period. About 80% of the total P
uptake is absorbed in the last 30 days of growth, and most of it is
finally translocated to the seeds. So when cowpeas are sown as a
sole crop and are not following a cereal crop in the same year,
phosphate application will be desirable in most parts of tropical
Africa. Depending on the availability of P in the soil, a dose of 20–40
kg P₂O₅/ha may be recommended. Though the potassium require-
ment of cowpeas is very high, they have considerable ability to draw
on the reserves of potassium in the soil and so do not always
respond to K fertilization. Fertilizers, if required, are to be applied in
bands below and to the side of the seed row.

**Water use**

All over tropical Africa, cowpeas are sown as a rain-fed crop. After
the cessation of rains, the crop thrives on the stored water in the soil.
The amount of stored water depends on the water-holding capacity of the soils. To obtain high yields, especially on soils with a poor water-holding capacity, and also if rain ceases early, irrigation is required. The plants should be kept well supplied with water from the beginning of flowering until the first crop of pods is well set.

Weed control
In the early growth stage, cowpeas must be protected from weeds. This is especially important when they are sown as a sole crop. Weeds can be removed by hand, by hoe, or by bullock-drawn implements (if sown on flat land). The best control measure is to kill the weeds with selective herbicides. Several herbicides are available and the following have been recommended for pre-emergence application: 1.5 kg a.i. metolachlor + 1.0 kg a.i. prometryne per hectare, or 1.5 kg a.i. metolachlor + 0.8 kg a.i. diuron per hectare.

Harvesting and threshing
Early-maturing cultivars produce a crop in about three months and late cultivars in about five months. The pods tend to ripen unevenly, hence several (4–6) hand-pickings are needed to prevent shattering and damage to pods and seeds by insects. The harvested pods must be dried to reduce the moisture content of the seeds to 10% for safe storage. Thoroughly dried pods are easily threshed by hand or with a conventional thresher.

Yields
Under traditional farming systems, cowpea yields vary widely between 250–1,000 kg/ha of dry grain. By adopting the recommended practices and good management, yields of between 1,500 and 2,000 kg/ha are easily possible.

Storage
Cowpeas are susceptible to serious damage by insect pests during storage. It is therefore important to dry the seed thoroughly before storing. All the containers and storage structures should be cleaned and also treated with suitable chemicals to destroy any insect pests they may harbour. Fumigation is also a good control measure.

Crop Protection
Diseases
Cowpeas are generally not as susceptible to epidemics of disease as many other grain legumes. The most important diseases are cowpea
wilt (*Fusarium oxysporum*), scab (*Sphaceloma* spp), brown blotch (*Colletotrichum capsici*) and *Septoria* leaf spot (*Septoria* spp).

To control these diseases, disease-resistant cultivars must be sown. Even then, whether there are symptoms of these diseases or not, precautionary measures should be taken. A mixture of 2.5 kg/ha Dithane M-45 (mancozeb) + 0.6 kg/ha Benlate (benomyl) applied weekly, beginning at 4–5 weeks, checks most diseases.

**Insect pests**

Cowpeas provide a source of food for a large number of different insects, all parts of the plant being susceptible to attack. The major insect pests are *thrips*, *flower beetles*, *pod-sucking bugs* and *Maruca testulalis*.

The pyrethroids (cypermethrin and deltamethrin) give good control of most pests except pod-sucking bugs. To keep these bugs under control, two timely applications of a systemic compound such as dimethoate are effective. This additional treatment also prevents aphid attack which can sometimes be severe late in the season.
COMMON (FIELD) BEANS
(Phaseolus vulgaris L.)

The term bean is broadly interpreted to include all field and kidney beans of any colour, size or shape, as well as lima beans and tepary beans. There are many species in the genus Phaseolus. They are listed below:

* *Phaseolus vulgaris* L. – common field or kidney or French bean
* *P. acutifolius* Gray – tepary bean
* *P. coccineus* L. – scarlet runner bean
* *P. aconitifolius* Jacq. – mat or moth bean
* *P. angularis* (Willd.) Wight – adzuki bean
* *P. calcaratus* (Roxb.) – rice bean
* *P. lunatus* – lima, sieva or butter bean.

Of these, the field bean (*P. vulgaris* L.) is the most important of the food grain legumes grown in the tropics and subtropics. It is the best known and most widely cultivated species of *Phaseolus*. Field beans are grown for their dry seeds and immature edible pods, and to a lesser extent for green-shelled beans.

Origin and Distribution
The common bean (*P. vulgaris*) is probably native to tropical South America. It was probably first cultivated with maize, and it seems likely that the two crops evolved together in a cereal-legume farming system in much the same way as cowpeas, sorghum and millet in West Africa. Shortly after the discovery of the Americas, the common bean was introduced to Europe, Africa and Asia by the Spanish and Portuguese. Now it is grown throughout the cooler tropics, but not in hot semi-arid or wet humid regions.

Area and Production
The leading countries in field bean production are India, Brazil, China, the USA and Mexico. In tropical Africa the crop is grown mainly in East Africa (Uganda, Tanzania and Kenya) although there is also appreciable production in Burundi, Rwanda and Cameroon.

Utilization
Dried beans are one of the most important sources of protein in the diet of many tropical people and supplement the carbohydrate staple foods of rice, maize and other cereals. As in other grain legumes, the protein in beans is somewhat deficient in the sulphur-containing amino acids (methionine and cystine), but is rich in lysine and tryptophan, which are deficient in cereals. Beans thus
complement the amino acids of cereals. Dried beans are eaten boiled, baked or fried, and are included in many soups. The immature pods and seeds of most kinds of beans are also eaten as a vegetable. The leaves and shoots of young plants are used as a potherb in some parts of the tropics and the straw is used as forage.

Some cultivars of beans and other food grain legumes have a reputation for causing flatulence (they generate gas in the digestive system) but it is reported that this can be alleviated by soaking them in water (adding 1/2 g of soda per litre of water makes the treatment even more effective) for several hours, discarding the soaking water, and then cooking them thoroughly in fresh water.

**Adaptation**

Beans are a warm-season crop: the optimum temperature for their growth is about 24°C. They are grown throughout the cooler tropics, but not in hot semi-arid or humid regions. Field beans require a minimum frost-free period of 140 days, as they are killed by frost. In general, high temperatures (20–32°C) during flowering cause the dropping of buds and flowers, which reduces yields.

Although beans are a warm-season crop, they do not require an excessive amount of moisture. Depending on the soil and climatic factors, the requirement is met with 300–600 mm rainfall. Some rain is required during the flowering and pod-setting stages. Dry weather is required for harvesting, drying and threshing the beans.

In East Africa, field beans are best suited to the medium altitude area from 900–2,100 m, although they are often found growing at altitudes as high as 2,700 m in parts of Kenya.

Field beans are adapted to a wide range of soils. They are grown most successfully on well-drained soils of medium texture (loams). The soil should be at least 1 m deep. In humid areas, they are grown on acidic soils.

**Botanical Description**

Although field beans are very variable, only two main kinds, 'bush' and 'climbing' are recognized. Bush cultivars are day-neutral, early-maturing, dwarf plants 20–60 cm tall with lateral and terminal inflorescences and consequently determinate growth. Climbing or 'pole' cultivars are indeterminate, and may grow 2–3 m tall if they have supports to climb by twining; among them are day-neutral and short-day types. In general, the bush types are preferred for commercial production because most of the crop ripens at the same time, thus facilitating mechanical harvesting.

The plant has a pronounced tap root which grows rapidly to a depth of 1 m. There are extensive lateral roots mainly confined to the
top 15–20 cm of soil. The bush-type plant has a strongly developed central stem and branches, bearing alternate trifoliolate leaves. The leaves and stems are somewhat hairy. The flowers are small and vary in colour from white to bluish; they are self-pollinated. The pods are 10–20 cm long, straight or curved, and terminate in a prominent beak. They contain 4–6 seeds, sometimes more. The seeds vary greatly in size (7–16 mm long) and colour (Fig. 58).

**Cultivation**

*Cropping systems*

The continuous cultivation of field beans in the same field may produce soil-borne diseases. It is advisable to grow them in long rotations with other crops, such as wheat, maize, sorghum and potatoes. In tropical Africa, beans are seldom grown as a sole crop.
They are usually interplanted with crops such as maize, sweet potatoes, cotton and coffee.

**Land preparation**

Land preparation for field beans follows the same general pattern as that for cowpeas. When they are to be grown as a sole crop, the land should be ploughed as early as possible in the season, the crop residues should be incorporated into the soil, and the field left in a suitable condition for the maximum storage of rain. Final land preparation, consisting of a deep ploughing followed by harrowing, is done a few days before sowing. The seed bed should be deep and firm, but to minimize crusting, it should be a little cloddy and not finely pulverized.

**Sowing**

The time of sowing field beans depends on the soil temperature. Generally, they are planted later than maize and sowing can be delayed until the soil temperature is about 18.5°C. When they are interplanted with maize, they are sown about 4–5 weeks after sowing the maize. Most beans are sown by dibbing 2–4 seeds per hole. Where a bullock-drawn plough is used (as in East Africa) seeds are sown into a shallow furrow and then covered. Field beans are usually sown in rows spaced 60–75 cm apart. Bush cultivars are sown at 8–10 cm apart in the row, whereas climbing cultivars are sown at 15–30 cm apart. The seed rate for the bush type with average spacing is about 60 kg/ha (100,000 plants per hectare); for the spreading type less seed (about 30 kg/ha) is needed. The planting depth ranges from 2.5–7 cm depending on the moisture status of the soil at the time of sowing.

**Water use**

Adequate moisture early in the season as well as during and immediately after flowering to pod filling is essential. Excessive water stress during the flowering and pod filling stages causes the shedding of a high percentage of flowers and pods, resulting in reduced yields. Irrigation during this period reduces flower and pod shedding and increases the size of the pods and seeds.

**Weed control**

Weeds should be removed while very small, before they can compete strongly with the bean plants. Smallholders rely on hand weeding while large-scale growers use implements to remove weeds. Chemical control measures are very effective. The herbicide recommendations for cowpeas also apply to field beans.
**Harvesting and threshing**

The beans are fully mature when the pods lose their green colour. If the cultivars are non-shattering, harvesting should be delayed until the moisture content of the seed has come down to 10%. If harvested earlier, the plants are allowed to dry either on the field or at the homestead. The plants are generally uprooted at harvest. When cultivation is done on a small scale, the harvested material is brought to the homestead, allowed to dry for about a week and then threshed with sticks. The haulms and pods are later removed by hand and by winnowing. On a large scale, threshing is done by heaping the plants on the ground and driving a tractor around on top of them, but it can also be done with a thresher.

**Yields**

In Africa, average yields are very low and are usually between 200 and 600 kg of dried seed per hectare. With improved cultivars and good management, including pest and disease control, 1,000–1,500 kg/ha may easily be obtained.

**Crop Protection**

**Diseases**

In humid areas, the crop suffers from many diseases, most of which are rarely a problem in the dry and semi-arid areas.

**Anthracnose** (*Colletotrichum lindemuthianum*) is one of the most destructive diseases of field beans world-wide. Elongated dark red cankers occur on the stem and leaf veins, and sunken spots with pink centres and darker borders appear on the pods. Cold wet weather favours anthracnose attack. It is carried by diseased seeds, so it is essential to use disease-free seeds, preferably from an arid area.

**Root rot** is caused by *Fusarium oxysporum*. The first symptom is a red discoloration of the tap root, which later turns brown, and the roots become dry and papery. There is no effective chemical control for this disease; the pathogen persists in the soil and only long-term rotation is truly effective.

**Rust** (*Uromyces phaseoli*) is also found world-wide. It produces reddish uredospores and later dark brown teleutospores, mainly on the leaves. This disease can only be avoided by growing resistant cultivars.

**Foliar blight:** field beans are also attacked by several bacteria that cause foliar blight. Control is achieved mainly through planting disease-free seed that is produced in a semi-arid environment.

**Common bean mosaic**, a seed-borne virus which is also transmitted by aphids from diseased to healthy plants, may cause losses in
all areas. The only effective control measure is the use of resistant cultivars.

**Insect pests**

Field beans are attacked by various insects, including bean weevils (*Bruchus* spp.), bean beetles (*Acanthoscelides obtectus*) and cowpea beetles (*Collosobruchus* spp.) that feed on the beans, as well as leaf hoppers, aphids, and such insects as the bean fly (*Meianagromyza phaseoli*) that transmit viruses.

Bean weevils are controlled through the use of weevil-free seeds for sowing and through the sanitation and fumigation of storage facilities. Outbreaks of plant-infesting beetles and larvae may be treated by dusting with malathion or other appropriate insecticides. To prevent initial infection by insects which transmit viruses from border plants, weed growth bordering the field should be eliminated before the bean crop is sown.
PIGEON PEAS

(Cajan cajan (L.) Mill spp.)

The pigeon pea, also known as red gram, arhar, tur, Congo bean and alberga is a very important crop among the grain legumes. It is an important legume of East Africa and although it is not so important in West Africa, it is becoming more popular there.

Origin and Distribution
The pigeon pea is an ancient African grain legume but the exact region of its centre of origin is not known. It has been cultivated in the Nile Valley for more than 4,000 years. Pigeon peas have also been cultivated in Madagascar from very early times. It appears that they were taken to India in prehistoric times, and this region now constitutes a centre of the greatest diversity of cultivars. The crop was taken to the New World in early post-Columbian days and pigeon peas are now grown widely throughout the tropics and subtropics.

Area and Production
India is the leading producer of pigeon peas, accounting for about 90% of the total world production. Though this crop is grown all over southern and south-eastern Asia, India, Pakistan and Burma are the biggest producers. In Africa, Uganda, Malawi and Tanzania are the major producers. Elsewhere in the world, the Dominican Republic, Venezuela, Puerto Rico and the West Indies are countries where pigeon peas are grown on a large scale.

Utilization
Pigeon peas are grown for the mature and immature seeds and pods, and for forage. They are also grown as a cover crop, a wind break, or a nurse crop for young cocoa, kola and oil palms.

Dry, ripe pigeon pea seeds contain about 57.3% carbohydrate, 19.2% protein, 7.5% fat, 8.1% fibre, 3.8% ash and 10.1% water. The calcium, phosphorus and iron contents are high, as are the vitamin contents (with the exception of vitamin C). Like other grain legumes, pigeon peas constitute a high-protein food, which serves to balance the extensive use of cereals and starchy foods in the human diet in the tropics and subtropics. Pigeon peas, like other legumes, are deficient in the amino acids methionine and cystine.

The mature dry seeds have a hard coat and are slower to cook than many other food grain legumes. Where pigeon peas are harvested green (before ripening) they are easily cooked and digested.
Adaptation
The cultivars of pigeon peas are extremely variable. They are either tall, long-duration and short-day types, or dwarf, day-neutral and short-duration types. It is a short-lived perennial, often grown as a warm-season annual. It has wide adaptability and grows especially well in subhumid regions and regions with long dry seasons. It is one of the most heat- and drought-resistant legume crops. Its drought-tolerance trait is best expressed where the soil permits deep and extensive rooting. Its deep root system permits good growth under semi-arid conditions with less than 650 mm of rain annually. It is less suitable for the very wet tropics. Most cultivars are very sensitive to frost.

Pigeon peas can be grown on almost all soil types, but prefer soils that are also well-suited to maize, sorghum or millet, i.e. light loams. They tolerate some alkalinity and salinity but they do not tolerate waterlogging. Among the food grain legumes, they appear to have the greatest capacity to meet their mineral requirements on less fertile soils because of the deep root system.

Botanical Description
_Cajanus cajan_ is the only cultivated species in the genus _Cajanus_. It occurs wild in Africa. It is a short-lived (2–3 years) perennial and bears seeds every year. It has a very deep tap root and a mass of lateral roots. The main stem is thick and erect, about 1 m tall in dwarf, day-neutral cultivars, but up to 4 m in tall short-day ones. It produces many ascending branches which give the plant a bushy growth habit. The leaves are trifoliate and the petioles are short and slender.

The inflorescences are small, terminal and/or axillary racemes. Flowering extends over several months. The pods are straight and flattened, usually 4–5 cm long, and have a pronounced pointed beak. In each pod, 3–4 seeds (rarely up to 8) are formed. There is much variation in the shape and colour of the pods, and the size, shape and colour of the seeds.

Pigeon peas are both self- and cross-pollinated. The pollen is shed the day before the flowers open. However, flowers are visited by bees and other insects, and about 20% (5–40%) cross-pollination can occur.

Cultivation
_Cropping systems_
The pigeon pea is a useful crop in a rotation as its deep root system opens the lower layers of the soil. It is considered particularly useful
when it follows an exhausting crop such as cassava and cereals. It fits well in rotations with wheat and sugarcane.

In West Africa, the intercropping of pigeon peas with yams, sorghum and maize is common practice. In Uganda, they are usually intercropped with finger millet and remain in the field after the millet has been harvested. In Kenya they are usually intercropped with maize and beans at the beginning of the rains and remain as a pure stand after the maize and beans have been harvested. In Tanzania they are always intercropped with cereals, roots and tubers.

The mixed sowing of cereals such as sorghum, maize and millet, and cotton with longer-season pigeon peas may produce greater total yields than either crops grown alone, because of more complete utilization of soil moisture and nutrients. For the following reasons farmers always prefer to grow pigeon peas with some other crops:

* since they take up two seasons (wet and dry), cultivators do not like to devote the entire land to a single crop of pigeon peas on economic grounds
* since the rate of growth is very slow in the beginning, they have no suppressive effect upon other quick-growing companion crops during the wet (rainy) season
* being a legume crop, they offer no competition to companion crops for soil nitrogen
* being a deep-rooted crop, they open up the subsoil to the benefit of the companion crops
* since they put forth a good canopy, they may provide shade to young crops such as cocoa, kola and oil palms.

**Land preparation**

Where pigeon peas are grown as a mixed crop, the land preparation done for the main crop will suffice, but the rows where pigeon peas will be sown should be well-pulverized and free from weeds as the early growth of this crop is very slow.

When pigeon peas are sown as a sole crop, the land must be thoroughly prepared. All the waste and weeds should be removed from the field and the clods should be broken. As pigeon peas do not tolerate waterlogging, the field should be well-levelled, and if possible, should slope slightly.

**Sowing**

The time of sowing depends upon the crop with which the pigeon peas are to be grown. Even when they are grown as a sole crop, they are sown after the establishment of rain. Short-duration cultivars may be sown a little later. The one important consideration is that
the crop flowers during the short-day period, so vegetative growth has to be completed before then. In other words, vegetative growth has to be completed before the rains stop. For a sole crop the seed rate is 15–25 kg/ha, while for mixed cropping it is 5–10 kg/ha.

Pigeon peas are sown in rows, whether they are sown as a sole crop or in a mixture with other crops. When sown as a mixed crop, the usual practice is to sow three of four rows of the other crop in between two rows of pigeon peas. In the case of a maize and pigeon pea mixture, the row spacing between the maize and pigeon peas may be 60 cm and between the pigeon peas it will be 120 cm. In this way both crops will be sown in alternate rows. Similarly, two, three or four rows of the main crop can be planted between two rows of pigeon peas.

As a sole crop it is sown in rows spaced 90–120 cm. Seed should be sown 30–45 cm apart in the row. In the case of intercropping, the row distance will be increased depending on the nature of the companion crop and how many rows of other crops are to be sown in between two rows of pigeon peas. Short-stature, short-duration and high-yielding cultivars of pigeon peas are sown very closely, about 25–30 cm both ways, in pure stand.

Fertilization

The wide soil adaptability of pigeon peas has led to the belief that they require little nourishment and that whatever amount they need they get from the soil. Although it is true that its deep and extensive root system gives the crop access to minerals not reached by shallow-rooted crops, this does not mean that the crop needs no further nutrients. It has responded well in fertilizer trials.

Being a legume crop, it may not require a large amount of nitrogenous fertilizer, but it requires other nutrients, namely phosphorus, potassium, calcium, magnesium and sulphur. Because of its very slow growth in the beginning, it needs nitrogen in the early stages of growth.

If pigeon peas are grown with well-fertilized maize, sorghum or cotton, there is no need to apply extra amounts of fertilizers for this crop. When grown as a sole crop, a dose of 20 kg N, 50 kg P₂O₅, and 30–40 kg K₂O per hectare may be given. If P is applied in the form of single superphosphate, this will meet the requirements of the secondary nutrients, i.e. calcium, magnesium and sulphur.

A practical and suitable method of applying fertilizer is placing it in bands below the seeds to give the growing plants continuing supplies of the mineral fertilizers during the growing season. Wherever possible, it is beneficial to apply organic manure for a long-season crop like pigeon peas.
Wood control
In the early stage of growth pigeon peas are suppressed by weeds, and in the later stages of growth they suppress weeds. In the early growth period, weeds provide serious competition and retard the development of the crop. Weed control is therefore essential for higher yields under all conditions, but particularly when soil moisture is limited. As pigeon peas are sown at wide spacing, inter-row cultivation with mechanical cultivators can be practised to save labour. This should be repeated two or three times.

A pre-emergence application of prometryne at 1 kg a.i./ha, or chloramben at 2–4 kg a.i./ha has been found very effective against broad-leaved weeds. EPTC or vernolate at 1–2 kg a.i./ha incorporated prior to planting can be recommended for the control of nutgrass and other annual grasses.

Harvesting
Harvesting is based on the flowering behaviour of the different pigeon pea cultivars. For early-maturing cultivars, the flowering period starts 3½ months after sowing, medium-maturing cultivars flower at approximately 4½ months, and late-maturing cultivars at about 5½ months. The duration of flowering ranges from 2–3 months, depending on the cultivar. In pigeon peas, all the stages of fruiting, i.e. flowering, unripe green pods and ripe pods are found together till the day of harvest. Harvesting is not delayed to allow all the flowers to form pods or all the pods to ripen because if it were delayed, most of the ripe pods would shatter. The crop is therefore harvested when the plant is still green but most of the leaves have dried and shed, and the majority of the pods are ripe. When the crop is grown on an annual basis, i.e. only for one year, the plants are cut at ground level, tied into bundles, brought to the threshing floor, stacked upright and dried for a few days. When the crop is grown as a perennial, harvesting is done by picking individual pods or by cutting off the pod-bearing branches.

Threshing is easy and is done either manually by beating the pods with a stick or beating the plants against any hard object, or by machine.

Yields
When pigeon peas are grown as a sole crop, the yield of dried seed ranges from 500–1,100 kg/ha but up to 2,000 kg/ha can be obtained with improved management practices. In mixed cultivation, yields of 250–800 kg/ha are obtained.
Storage
Before storing, the grains should be thoroughly dried. All the containers and storage structures should be cleaned and treated with an effective insecticide and the seeds should be fumigated just before they are stored. Whenever there is evidence of reinfestation during storage, fumigation should be repeated.

Crop Protection

Diseases
The most common disease of pigeon peas is wilt caused by the fungus *Fusarium udum* which interferes with the upward movement of water in the plant, causing it to wither and wilt. The disease can be recognized by the blackened stems which can be seen after peeling off the bark. With time, the black streaks spread to the lower parts of the plant. Control measures consist of using wilt-resistant cultivars and of not growing pigeon peas on the same land year after year, as the pathogen is soil-borne. Good crop rotation minimizes the risk of wilt attack.

Insect pests
Pigeon peas are attacked by several insects, the most prominent ones being the pod caterpillar (*Exelasta parasita*), the pod fly (*Muscidoe acaelypratoe*), the leaf caterpillar (*Eucelis critica*) and the pod borer (*Ancyllostostia stercorea*). The pod caterpillar attacks the pod, eating the seeds one after the other from outside the pod; the larvae of the pod fly damage the seed; the leaf caterpillar attacks the upper leaves of the plant; and the pod borer feeds on the developing seeds in the pod, making them unfit for consumption.
FIELD AND GARDEN PEAS  
(Pisum sativum L.)

Although the pea is an important pulse crop, it is not as important in tropical and subtropical regions as the other grain legumes described in this book. Peas and soybeans are grown on a large scale in the temperate and cooler areas of the world. In tropical Africa, pea cultivation is mainly done on the highlands during the cold season.

Origin and Distribution
There are two views on the centre of origina and diversity of the field and garden pea (Pisum sativum). One is that it evolved in the Mediterranean area and in Central Asia, the other is that it originated in Ethiopia, and from there spread to the Mediterranean region in prehistoric times. The cultivation of field peas can be traced to the Swiss lake dwellers about 300–1,100 BC. From the Mediterranean region it spread to India and China and other temperate countries of Europe and the USSR. The pea (if it did not originate there) reached the mountain regions of Ethiopia and East and Central Africa before the arrival of the Europeans. Peas were brought to North America by the early colonists.

Area and Production
The total area and production of peas in the world in 1989 were 10 million hectares and 16.5 million tonnes, respectively. The area and production of peas in Africa for the same year were 0.45 million hectares and 0.27 million tonnes, respectively. The important countries in the world for pea production are the USSR, France and China; in tropical Africa they are Ethiopia, Zaire and Burundi.

Utilization
Peas are a high protein food, but like other grain legumes they are somewhat deficient in the amino acids methionine and cystine. Peas are also a valuable supplement to cereals and other starchy root and tuber foods in the human diet, because of their high lysine and tryptophan contents, amino acids in which cereals are deficient. Peas are also rich in calcium, phosphorus, iron and vitamins, with the exception of vitamin C, which can, however, be obtained by letting the seeds germinate and eating the sprouts. Being very rich in protein, peas may be used as a substitute for animal protein, which is usually in short supply in the diet in the tropics.

The dried grains are a good food for humans. They are either used whole, split ('dal'), or as flour. The grains may be boiled or fried, or
allowed to germinate and eaten as sprouts. A good number of sweet and savoury dishes can be made from the flour. The green grains are cooked and eaten as a vegetable, but they can also be eaten raw. They can be canned or frozen and are the leading frozen vegetable in the USA and Europe. The green leaves and tender branches are used as a pot-herb in many Asian and African countries. The plants and straw are used as forage, hay and silage. Peas are also grown as green manure.

**Adaptation**

Peas are best adapted to cool climates with moderate rainfall. Moderate temperatures are essential throughout the growing season for successful production. They survive light frosts, but not during flowering. Hot dry weather interferes with seed setting. Peas are grown in the winter (cooler) season in the tropics and are an important crop of higher elevations (more than 1,000 m), in particular in East Africa and Zaire.

Peas are best adapted to well-drained, clayey loam soils. They tolerate a moderate soil pH range; the optimum is 6.5 but moderate acidity (pH as low as 5.5) is tolerated. They do not tolerate waterlogged conditions.

**Botanical Description**

Peas belong to the genus *Pisum*. The pea is an annual herbaceous plant, with a climbing or half-bush growth habit, reaching a height of 50–150 cm. The plant develops a tap root system with many slender laterals. The stems are weak, slender and succulent. The leaves are typically pinnately compound, but the apical leaflet is modified into a split, or double tendril. A large pair of stipules, or leaflike bracts, is found at the base of the petiole of each leaf. The flowers are usually borne singly in leaf axils, although cultivars with pairs of flowers may be preferable to those with single flowers. The flowers vary in colour from white to reddish purple. The pea plant is long-day in photoperiodic response and flowers indeterminately throughout the growing season. The fruit is a typical pod, and contains four to nine seeds. Seeds vary in shape from round to angular, and in colour from green-yellow to grey and brown. Garden peas are uniformly light green.

**Cultivation**

*Cropping systems*

Under irrigated conditions peas are grown as a sole crop and under rain-fed conditions they are usually intercropped with cereals such as wheat, barley and oats. For fodder purposes, they are usually
grown with oats. Peas fit well in rotation with maize, sorghum and cotton as these crops are grown during the wet summer season and peas are grown in the winter season.

**Land preparation**
Peas do not require a very well-ploughed land and one or two ploughings are adequate. Large clods should be broken down but not too finely.

**Sowing**
Peas are sown soon after the rains have ceased and the winter season starts, i.e. during October-November in Asia and northern Africa and during April in East Africa and other countries in the southern hemisphere. The seed rate varies from 60–90 kg/ha, depending on cultivar, size of seed and plant density. The seed is sown in rows either behind the plough or with a seed drill. Row spacing may vary from 20–30 cm. The desired stand (300,000 plants per hectare), can be obtained only by sowing seed at 10–15 cm apart in the row.

**Fertilization**
If peas are to be grown in any field for the first time, seed inoculation is necessary. The seed should be inoculated with an appropriate strain of *Rhizobium* to ensure effective nodulation.

If inoculated, peas do not need a nitrogen fertilizer. Occasionally a small dose of 20 kg/ha may be applied to boost early growth. However, peas have a high requirement of phosphorus, potassium, calcium, magnesium and sulphur. Most soils are rich in potassium, thus the application of ordinary superphosphate at the rate of 50–60 kg/ha will meet the requirements of phosphorus, calcium, magnesium and sulphur. If potassium is not sufficiently available, it should be supplied at 30–40 kg K₂O/ha.

**Water use**
As the pea is not as deep-rooted as the other grain legumes, the availability of water in the root zone throughout the growing season is always beneficial. It has been reported that the moisture content must not be allowed to drop below 60% of field capacity during the period from emergence to just prior to flowering; and not below 90% from the start of flowering until the main flowering period.

**Weed control**
Normally there is not much competition from weeds once the crop is well established, but it is always useful to remove or kill all weeds when the peas are in the very early stages of growth.
**Harvesting and threshing**

Harvesting should be done when the pods are mature and dry, and when the moisture content of the grain is about 10%. Harvesting should not be delayed otherwise the pods will shatter.

Chapman and Carter (1979) have reported that the use of chemical desiccants to hasten the drying of the plants and to facilitate harvesting has become increasingly popular in the USA. Sulphuric acid solutions and several commercial herbicides have been used as desiccants. The use of desiccants, however, may contaminate the crop residue (haulm) and make it unfit for use as livestock feed.

Threshing may be done by beating the plants with a stick, having bullocks tread on them, or driving a tractor over the harvested material.

**Yields**

The average pea yield in the world is about 1,600 kg/ha. In a favourable climate and with good cultural practices, the yield can easily be increased to three times the average.

**Storage**

The grains should be dried thoroughly before storage and the moisture content should not be higher than 10%. The grains should also be fumigated before storage. All the containers and storage structures should be cleaned and treated with an effective insecticide.

**Crop Protection**

**Diseases**

Peas are subject to attack by powdery mildew caused by the fungus *Erysine polygoni*. There is no known practical control for this disease. Peas are also susceptible to root rot and to wilt diseases caused by various fungi. Symptoms of leaf blotch, caused by the fungus *Septoria pisi* appear on the leaves of seedlings. Peas are also susceptible to bacterial blight, caused by *Pseudomonas pisi*. Control measures against these diseases include crop rotation, the use of disease-free seeds, the use of resistant cultivars, and the use of the available suitable fungicides.

**Insect pests**

The pea weevil (*Bruchus pisorum*) is the most serious insect pest of field peas. The female deposits eggs in the developing pod, and when the eggs hatch, the larvae feed on the seed. The feeding activity of the larvae reduces the nutritional and market value of the seed. Control consists mainly of fumigating the seeds immediately after harvesting but occasionally it may require field spraying to destroy the females before they deposit their eggs.

Other insect pests include pea aphids and the pea moth.
CHICK PEAS (GRAM)
(Cicer arietinum L.)

Origin and Distribution
Gram is an ancient crop; perhaps it is the oldest pulse crop cultivated in both Asia and Europe. It is not known in a wild state, but appears to have originated in Western Asia and to have spread at a very early date to India and Europe. According to de Candolle, the fact that gram has a Sanskrit name, 'Chana', indicates that this crop has been under cultivation in India longer than in any other country. The crop was also known to the ancient Egyptians, Hebrews, and Greeks. It has been introduced in recent times to tropical Africa, Central and South America, and Australia.

Area and Production
The total area and production of gram in the world during 1989 were 9.9 million hectares and 7.4 million tonnes, respectively; the area and production for Africa during 1989 were 0.4 million hectares and 0.3 million tonnes, respectively. India, Turkey and Pakistan are the important countries for its production. In tropical Africa, Ethiopia is the leading country for gram production. It is also grown in Tanzania.

Utilization
Like other legumes, gram is somewhat deficient in the amino acids methionine and cystine, but rich in lysine and tryptophan. It is a useful supplement to cereals and other starchy foods. It is rated as being highly digestible, particularly the white and cream-coloured seed types.

The dried grain is used in many ways. The whole dried seeds are eaten boiled. 'Dal' is made by splitting the seed and removing the seed coat. Gram flour is made by grinding the seed after the coat has been removed and is used to make many sweet and savoury dishes. The tender shoots and green pods are used as vegetables. The fresh green grains are eaten raw or cooked as a vegetable. Green gram seeds are also canned. The green plants are used as forage. After harvesting and threshing, the chaff is fed to livestock. The grain is also fed to animals, especially horses and bullocks.

An acrid liquid from the glandular hairs of the plants is collected by spreading a cloth over the crop at night. The cloth absorbs the exudation with the dew. The exudate contains about 94% malic acid and 6% oxalic acid and is used medicinally.
Adaptation
Gram is adapted to cool and moderate temperatures during its growing period, but tolerates considerable heat during the fruiting and ripening period. Early summer heat shortens the growing period, hastens maturity and reduces yields. Gram is tolerant to drought but does not grow well in warm, humid climates. In Asian countries it is sown in winter (October-November) and grows on the moisture conserved in the soil. In the Asian and Mediterranean countries where gram is grown, there is little rainfall during the growing season. Light to moderate rainfall is good for the crop, but not heavy rainfall. Rainfall during the early growth period is more beneficial than during the flowering period. Frost during flowering and fruiting is very detrimental to the crop.

Gram is grown on a wide variety of soils. It does not tolerate wet soils. The most suitable soils are moderate to heavy, well-drained soils, i.e. clay loams and loams. High fertility in the soil stimulates excessive vegetative growth at the expense of seed production. Gram is notably tolerant to soil salinity.

Botanical Description
Gram is an erect herbaceous annual, rarely taller than 60 cm. The whole plant is covered with glandular hairs. It has a strong tap root and a mass of lateral roots in the upper layers of the soil. The plant is well branched with pinnate leaves about 5 cm long, with 10–20 leaflets. The flowers can be of many colours and are borne singly on long axillary peduncles. The pod is 2 cm long and 1 cm broad and contains 1–3 spherical, wrinkled seeds with an oblique, pointed beak. The seeds are commonly brown, but sometimes white, red or black. Brown- or black-seeded types are more tolerant to adverse soil and climate conditions, whereas white-seeded ones, although high-yielding, do well only under more favourable conditions.

Gram is a self-pollinated crop although occasional cross-pollination occurs. On cloudy and wet days little pollination takes place and empty pods result.

Cultivation
Cropping systems
Gram can be grown either as a sole crop or intercropped with crops such as wheat, barley, linseed and mustard. Where rainfall distribution permits double cropping, gram follows the principal wet (rainy) season crop such as maize, sorghum or rice. Quite often it is grown as a relay crop and planted in a standing crop of cotton. Where rice is grown as a transplanted crop, gram is sown soon after the rice is harvested.
Land preparation
Being a deep-rooted crop, gram does not need a fine seed bed. Unlike most other winter crops, it requires a somewhat cloddy seed bed and one or two ploughings are enough to prepare the land for gram sowing. The soil should be moist to a considerable depth.

Sowing
Where gram is grown as a rain-fed crop (which is the usual situation) the optimum sowing time is after the rain has stopped and winter has just started, i.e. from the end of October to early November in the northern hemisphere, and in April in the southern hemisphere. Earlier sowing is associated with excessive vegetative growth, causing reduction in the yield of grain. Late sowing may cause poor emergence of plants because of a shortage of water in the soil. Under irrigation, gram is sown at the beginning of the cool season.

The seed rate varies from 40–60 kg/ha. Where there is an adequate supply of moisture, closer sowing is preferred and hence a higher seed rate. For cultivars with a bigger seed size, a higher seed rate will also be needed.

Row sowing is recommended. Depending on cultivar, inter-row spacing varies from 25–40 cm and intra-row spacing varies from 15–30 cm. Gram is sown 4–10 cm deep, depending on the moisture status of the soil.

Fertilization
Gram does not require nitrogen when naturally or artificially inoculated with root nodule bacteria. It certainly needs other nutrients, mainly phosphorus, and an application of 40–50 kg P₂O₅/ha may be recommended. Where there is a shortage of potassium in the soil, a light dose of 20–30 kg K₂O/ha may be applied.

Where gram is sown deep (8–10 cm) under conditions of limited moisture, side placement of fertilizers is recommended, and when it is sown shallow (3–5 cm), deep placement of fertilizers is recommended. These methods of application minimize phosphate fixation in the soil.

Water use
Gram is usually grown as a non-irrigated crop but when it is grown mixed with wheat, one to two irrigations may be given. Excessive irrigation may result in poor aeration in the root zone (not conducive for bacterial growth) and should therefore be avoided. In heavy soil the land should be intercultivated after irrigation so as to provide oxygen in the root zone.
Topping (Nipping)
Topping entails nipping off the tops of the plant to encourage branching and is done when the plant is still young. It is controversial whether topping helps to increase the yield of the crop or not. However, topping does not adversely affect the yield, and the tops (tender stems and leaves) so removed are used as a vegetable.

Harvesting and threshing
Of the pulse crops, gram has the least problem with shattering. The crop should therefore be allowed to dry completely in the field so that the moisture content of the grain is reduced to about 10%. If, for any reason, harvesting is done earlier, the harvested material should be left to sun-dry on the threshing floor. Harvesting is done by pulling the entire plant from the soil.

Threshing is done by beating the dried plants with a wooden stick. Large-scale threshing is done by having bullocks trample the dried plants, or by driving a tractor over them. Winnowing is done to separate the grains from the chaff.

Yields
The average yield of rain-fed gram ranges from 600–1,000 kg/ha. However, yields higher than this can easily be achieved with correct management of the crop.

Storage
Before storing, the grains should be dried to a moisture content of no higher than 10%. All empty containers and storage structures should be cleaned and treated with effective insecticides. The grains must be fumigated before being put into storage and whenever there is any indication of reinfestation during storage, fumigation should be repeated.

Crop Protection
Diseases
Gram is attacked by wilt and by many leaf and stem diseases. These are most serious in periods of continuing rains and high humidity, particularly at higher temperatures. The important diseases are gram blight (Mycosphaerella rabiei), wilt (Rhizoctonia baticola) and gram rust (Uromyces cicerisarietine). To minimize damage from diseases the following practices should be adopted:

* plant resistant cultivars
* practise crop rotation so that gram is not grown in the same field year after year
* use disease-free seeds
* destroy diseased debris either by burning or burying underground
* provide sufficient soil moisture at the time of sowing and flowering.

**Insect pests**
The most damaging insects are cutworms, leaf miners, pod borers, weevils and thrips. It does not follow that all these pests will attack the crop every year and everywhere. Most of them become a problem when humidity is high. Clean cultivation and the use of resistant cultivars should be encouraged as methods of controlling the pests.
13
OIL-SEED CROPS

The use of vegetable oils, i.e. oils derived from the seeds of plants, began before recorded history. Unlike cereal crops and some grain legumes, the cultivation of oil-seed crops has not played a significant role in mankind's cultural development, although several important species of oil-seed crops are grown throughout the world.

Oil-seeds are one of the oldest products of this earth and one of the principal sources of oils and fats. Oils and fats provide nourishment, energy and warmth to the human system. Some of them are very rich in protein and are used in many forms. Oils and fats are chemically similar, but they differ physically; at normal temperatures oils are fluid, whereas fats are solid and become fluid only when heated.

Oils from oil-seeds are also used in the manufacture of hair oils, soaps, toiletries, paints, varnishes, etc. Long before kerosine oil, gas and electricity were in use, vegetable oils were being used to provide light in homes. Oil in the form of lubricants keeps the wheels of machinery in motion. Oil-seed cakes are used as cattle and poultry feed and manure. Soybeans and groundnuts, being legume crops, enrich the soil.

The kind of oils produced by plants are the non-volatile oils and the 'essential', volatile oils. The first kind of oils are a food reserve and are by far the most important in commerce. The second kind of oils are aromatic and are commercially important in scents and perfumes. Millions of tonnes of non-volatile vegetable oils are consumed as food or used in industry each year. They are used either as fluid oils or converted into edible fats such as margarine. Edible fluid oils are converted into edible fats by a process of catalysed hydrogenation in which relatively unsaturated oils become more saturated by combining them with hydrogen. Large quantities of vegetable oils are used to make soap and detergents. Vegetable oils are also used as lubricants and the least saturated of them are used in paints and varnishes and to make linoleum.
The fixed, non-volatile vegetable oils are produced either from the seeds of field crops or the fruits of some trees, or as by-products.

Field crops
The following are important field oil-seed crops:

* soybean (*Glycine max*)
* sunflower (*Helianthus annus*)
* groundnut (*Arachis hypogaea*)
* rape-mustard (*Brassica* spp.)
* sesame (*Sesamum indicum*)
* linseed (*Linum usitatissimum*)
* castor (*Ricinus communis*)
* safflower (*Carthamus tinctorius*)
* niger (*Guizotia abyssinica*)

Trees
The following are the important tree crops which provide vegetable oils:

* oil-palm (*Elaeis guineensis*)
* tung (*Aleurites* spp.)
* coconut (*Cocos nucifera*)
* olive (*Olea europaea*)
* shea butter (*Butyrospermum paradoxum*)
* cocoa (*Theobroma cacao*)
* mahua (*Bassia latifolia*)
* neem (*Melia azadirachta*)

By-products
Vegetable oil is also obtained as a by-product, from the seeds of:

* cotton (*Gossypium* spp.)
* maize (*Zea mays*)
* tomato (*Lycopersicum esculentum*)
* water melon (*Citrullus lanatus*, a bitter-fruited wild form found in Africa, with edible seeds)
* melon (*Cucumis melo*)
* citrus (*Citrus* spp.)
* rice (*Oryza sativa*).
The oil content of the various oil-seed crops is given below:

<table>
<thead>
<tr>
<th>Crop</th>
<th>Oil content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soybean</td>
<td>19</td>
</tr>
<tr>
<td>Sunflower</td>
<td>46</td>
</tr>
<tr>
<td>Groundnut</td>
<td>44–50</td>
</tr>
<tr>
<td>Sesame</td>
<td>40–45</td>
</tr>
<tr>
<td><em>Brassica juncea</em></td>
<td>35–41</td>
</tr>
<tr>
<td><em>B. campestris var. sarson</em></td>
<td>45</td>
</tr>
<tr>
<td><em>B. campestris var. toria</em></td>
<td>45</td>
</tr>
<tr>
<td><em>B. napus</em></td>
<td>32–40</td>
</tr>
<tr>
<td>Linseed</td>
<td>37–43</td>
</tr>
<tr>
<td>Castor</td>
<td>50</td>
</tr>
<tr>
<td>Safflower</td>
<td>24–36</td>
</tr>
<tr>
<td>Niger</td>
<td>38–50</td>
</tr>
</tbody>
</table>
GROUNDNUTS
(Arachis hypogaea)

Groundnuts, also called peanuts, monkey-nuts and earthnuts, are grown as an oil-seed and grain legume crop. They are a major cash crop and widely grown in practically all the tropical and subtropical regions of the world for direct use as food, for oil, and for the high protein meal produced after oil extraction.

**Origin and Distribution**
The exact origin of the groundnut is as yet unknown. At present the evidence seems to favour the upper Plata basin of Bolivia as the home of this legume. The leading systematist Krapvickas (1968), who studied the genus through South America for two decades, reported that groundnuts most likely originated in eastern Bolivia at the foothills of the Andes. In this area there is a very important centre of variability for the subspecies hypogea.

Portuguese navigators introduced groundnuts from South America to Africa, India and possibly other areas. It is probable that the groundnut moved up the coast from Peru to Mexico, and thence across the Pacific to China and Indonesia. In all these lands the groundnut became readapted and specialized and then returned to tropical America and the United States.

**Area and Production**
Groundnuts are widely grown as a crop of major importance in many countries of the tropics and subtropics. The area and production of groundnuts in the world during 1989 were 20.1 million hectares and 22.6 million tonnes, respectively. The area and production of groundnuts in Africa during 1989 were 5.3 million hectares and 4.6 million tonnes, respectively.

In Asia the main producers are India, China, Myanmar and Indonesia; in Africa the main producers are Senegal, Nigeria, Zaire and Sudan; in South America they are grown mainly in Argentina and Brazil; and in Central and North America they are grown mainly in the USA and Mexico.

Nearly three-quarters of all groundnuts grown in the world are produced by India, China, the USA, Senegal and Nigeria. Africa is an important continent for groundnut production as it produces 20% of the total world crop. In Africa, groundnut cultivation is confined mainly to tropical countries.

**Utilization**
Groundnuts are a highly nutritious food; whole groundnuts and groundnut meal, produced by expressing the oil, are rich in protein,
minerals and vitamins. The average chemical composition of shelled groundnuts is approximately 11.7% carbohydrate, 30.4% protein, 47.7% oil (fat), 2.5% fibre, 2.3% ash and 5.4% water. Decorticated groundnut cake contains about 23.2% carbohydrate, 46.8% protein, 7.5% fat, 6.4% fibre, 5.8% ash and 10.3% water. The oil contains about 53% oleic acid and 25% linoleic acid. Groundnuts are rich in calcium, phosphorus and iron and they constitute an excellent source of the vitamins thiamin, riboflavin and niacin, but not of vitamin A or C. On a percentage basis, the meal is much richer than the whole groundnut in protein, minerals and vitamins.

The groundnut protein resembles most other grain legumes in being rich in lysine and tryptophan, but deficient in methionine and cystine. Groundnut protein therefore serves as an excellent supplement to cereals and other starch crops that are comparatively high in methionine and cystine, but low in lysine and tryptophan.

Groundnut oil is a high-quality, non-drying oil that is used in the preparation of hydrogenated cooking fats and frying oils; a fraction that settles out during the manufacturing process is used for making soap.

About 55% of shelled groundnuts in the USA is used annually to make groundnut butter. The butter is produced by grinding roasted groundnuts and mixing them with other ingredients. Groundnut butter is very rich in fat content. Groundnuts, either in the pod or shelled, are a popular confection and party snack. They are also used in making many kinds of candies. About 25% of the total groundnuts consumed annually are roasted and salted and eaten as a snack.

After the oil has been extracted, groundnuts are milled into a fine flour for baking. The flour is an excellent source of good quality protein. It is frequently mixed with wheat flour and used for bread and other bakery products, as well as in beverages. Groundnut beverages for infant feeding have been developed in India.

The cake left after the removal of the oil from groundnuts contains about 50% protein, and is widely used in concentrated livestock feeds. Groundnut hay contains about 7% protein. Its value depends mainly on the care with which the crop was cured, and in particular on the amount of leaves retained.

Adaptation
Groundnuts are grown to 40° N and S of the equator, where annual rainfall is 1,000 mm or more, with half of that during the growing season, and is followed by a distinct dry season during which the pods ripen and mature. Groundnuts are a warm-season crop and
need abundant sunshine and a warm climate for their normal growth. They are killed by frost. With adequate irrigation, they can be successfully produced in drier regions. Although the plant requires adequate moisture throughout its life, the pegging and fruiting periods are critical times when adequate moisture should be available. Excessive moisture and high temperatures reduce yields.

The most suitable soils are well-drained, loose, friable, sandy loams, well supplied with lime and with moderate (but not high) amounts of organic matter. The 'pegs' penetrate these soils easily and harvesting can be done with minimum losses. Good yields of groundnuts can also be obtained on fairly heavy soils, provided they are rich in organic matter and in good tilth. The optimum pH range is from 6.0–6.5. Seedlings can tolerate salinity better than the mature plants.

**Botanical Description**

Groundnuts have a well-developed tap root with numerous lateral branches. Some adventitious roots emanating from the hypocotyl and aerial branches are also found. The smaller roots are mostly produced between depths of 10 and 25 cm in the upper soil layer, though the primary root grows to a depth of 90–120 cm in loose soils.

The groundnut plant has a central, upright stem and many lateral branches. In runner types, the laterals are prostrate, and in bunch types they are more or less erect in the young plants but tend to become prostrate at a later stage. The plant has pinnately compound leaves which are usually composed of two pairs of leaflets (Fig. 59). Groundnuts are reproductively day-neutral plants. They begin to flower 4–6 weeks after sowing, with a peak of flower production 10–12 weeks after sowing.

The flowers are small, yellow and grow singly or in clusters of 2–4 close to the ground and occasionally even underground. They are complete and self-pollinated. After pollination and fertilization, the region immediately behind the ovary begins to elongate and grows downwards. This region, called the gynophore or peg, pushes the ovary at its tip into the soil, where the groundnut fruit grows and matures. Groundnut plants flower profusely but the proportion of ovaries that develop into mature fruits is usually small, around 1–20%. Only two-thirds of the total number of pods produced reach full maturity. The late-formed pods which do not reach maturity by the time of harvest are the so-called 'pops' that have to be removed before the pods are stored.

The fruit is a pod and consists of a shell containing 1–3 seeds.
(occasionally up to 6). The papery seed coat is extremely thin; its outer layer is coloured pink, red or brown. The seeds have two plump cotyledons. The shell is generally reticulate and shows constrictions between the seeds (Fig. 60). The shell consists of three layers; the outer layer is spongy, the central layer is fibrous and the inner layer is thin and parchment-like. The shell constitutes about 30–40% of the total weight of the fruit.

**Types of groundnuts**

Groundnuts are classified into two main groups, according to their habit of growth.

**Spreading or runner types:** in cultivars belonging to this group, the gynophores ('pegs') are distributed from the basal to the terminal region of the branches, or occur in clusters along these branches, up to 40 cm from the base of the plant. As the branches grow more or less prostrate on the ground, the pods are scattered underground in a relatively large area around the base of the plant. Cultivars of this group are generally very productive and have large kernels. The
harvesting of these cultivars is difficult, however, and many pods are left in the soil.

**Bunch type:** cultivars of this group grow erect. The pods are clustered around the base of the plant and mature at about the same time. The pods and kernels are small, and the individual plants are not very productive. They are easier to harvest, however, and better suited to inter-row cultivation.

**Cultivation**

**Cropping systems**
Groundnuts are an extremely soil-exhausting crop when the nuts and the entire top-growth are harvested. Where the top-growth is buried in the soil after removing the nuts, the effect on the soil is less harmful. Yields decline rapidly when groundnuts are grown continuously on the same land. Furthermore, the continuous cultivation of groundnuts on the same land leads to a build-up of organisms causing root-rots and pod-rots. Groundnuts should therefore not be grown on the same land year after year, not even for two successive years. Because of their ability to use fertilizer residues left in the soil from the previous season’s crop, groundnuts are
a good crop to follow a heavily fertilized crop such as maize, cotton or sorghum.

The intercropping of groundnuts with millet, sorghum and maize is practised under rain-fed cultivation all over tropical Africa. It has been reported that intercropping groundnuts with these cereals gives somewhat higher overall yields, and a better response to fertilizers, than the individual crops grown as sole crops.

**Land preparation**

Groundnuts require a loose and friable soil, into which the pegs easily penetrate, and which prevents excessive loss of nuts during harvesting. To achieve this, the soil should be thoroughly and completely prepared to a depth of 25–30 cm before planting. The stubble from the previous crop should be thoroughly incorporated well in advance of sowing. All the weeds should be destroyed during land preparation. A final disk and levelling just before sowing completes preparation.

**Seed treatment**

Groundnuts suffer from seed-borne diseases and to control these, groundnut kernels must be treated with appropriate fungicides such as Aldrex T (aldrin and thiram) or Fernasan D (thiram). Although seed treatment does not ensure complete and long-lasting protection, it does prevent initial losses and thereby ensures a full stand.

One of the most critical factors limiting the yields of groundnuts in Africa is low plant-population densities (20,000–25,000 plants/ha). Recommendations for plants populations vary widely, from 100,000 plants/ha to 350,000 plants/ha. On the average, a seed rate of 40–60 kg/ha of shelled kernels should be sufficient for normal planting. Planting should be done at inter- and intra-row spacings of 30–45 cm and 15–25 cm, respectively. Planting at these spacings will produce 100,000–200,000 plants/ha.

The main groundnut crop is rain-fed and is planted during the rainy season. In the drier regions of tropical Africa, the incidence of rainfall determines the time of sowing. The soil must be sufficiently moist before sowing can start and this is possible only when rainfall is well-established. Sowing should be done as soon as the rains are well established as delayed sowing causes reduced yields and late harvesting. Where rosette disease is a problem, as in Nigeria, early-sown crops may escape infection (Yayock, 1976).

In Nigeria it is common practice among the farmers to plant groundnuts on ridges 1 m apart. They plant 1–3 kernels in holes on the ridges at a distance of more than 30 cm. If they cannot be
persuaded to reduce the distance between ridges, they should at least be persuaded to sow at closing spacing, say 20 cm, on the ridges.

For small areas, groundnuts are dilled by hand, but planters are used for the mechanized sowing of large areas. The sowing depths range from 2.5–4 cm in heavier soils and 6–8 cm in lighter soils or when large seeds are used.

**Fertilization**

Groundnuts remove relatively large amounts of certain nutrients from the soil, especially when the entire plant is removed from the soil. The nutritional management of groundnuts is very different from that of cereals or grain legumes. Experiments with fertilization of the crop reveal many inconsistencies in its response to fertilizers. Failure to obtain marked responses to the application of fertilizers directly to the crop has often led to the conclusion that fertilizers do not pay. Groundnuts can use the residues of fertilizers applied to the preceding crop, and can take advantage of minerals that are not easily available to the other crops. This capacity may be due in part to the extensive root development of the plant and may also be the result of some enzyme-like secretion from the roots, which makes minerals bound to soil particles available to the plant. In many cases it has been found advisable to use a part or all of the fertilizer on the previous crop in the rotation, instead of directly on the groundnuts (Kipps, 1970).

Groundnuts, like other legumes, can fix atmospheric nitrogen and therefore nitrogen fertilization is rarely required. A proper balance of nitrogen and phosphorus is essential for early maturity. However, if the preceding crop before groundnut is well-fertilized, there will be no need to apply N, P or K. When groundnuts are grown with cereals, the fertilizer applied for the cereal also meets the requirements of the groundnuts. If the preceding crop was not well-fertilized, 40–60 kg P₂O₅ and 40 kg K₂O/ha may be applied. However, the application of calcium and boron are very important. Calcium fertilization, in addition to liming to increase soil pH, is also important as adequate available calcium is essential for high yields and disease resistance. Boron affects the entire growth and development of the plant. Adequate available boron fosters a concentrated flowering period and a crop that matures uniformly. Boron deficiency may extend the flowering period and lead to malformed foliage (Chapman and Carter, 1979).

**Water use**

In many areas and at many times, supplemental watering has avoided disastrous yield losses in a dry year. Water stress invariably
affects plant growth and development. Early vegetative growth, flowering and pegging, and pod maturation are the stages when the crop is most sensitive to water stress.

Groundnuts have an unusual relationship with the soil as it must supply water to the roots and also allow penetration of the gynophores (pegs). It seems unlikely that much water could be absorbed by the pegs once they are in the soil (Klepper, 1973). There should be a regular and adequate supply of available moisture either by rain or by irrigation. The crop is harvested after the rains have stopped. By the time the crop is harvested, the soil has become too hard to remove the pods. A light irrigation should therefore be given a few days before harvesting so that harvesting is facilitated and harvesting losses are minimized.

Weed control
Weeds can be a serious problem in groundnut cultivation as they may reduce yields in three different ways: through competition; by interference with the harvest; and by harbouring pests (Fig. 61).

Cultural practices such as crop rotation may be used to prevent the build-up of troublesome weeds or to provide an opportunity for their eradication. Alternatively, the land may be cultivated before
planting so that the weed seed and organic debris are buried at least 8 cm deep. If the groundnuts cannot be planted immediately after this, a shallow cultivation is required to control newly emerged weeds just before planting.

When weeds appear after planting they may be removed by hand-pulling, hand-hoeing, or with a bullock- or tractor-drawn cultivator. Two or three cultivations or hoeings between the rows at intervals of 15 days are advocated, but no interculture should be undertaken after the plant has started appreciable pegging.

Weeds can also be controlled with herbicides. These can be either pre-sowing, pre-emergence, craking time (the point at which the groundnut plants are just beginning to emerge) or post-emergence applications. Terbutryn and metolachlor are the most effective herbicides for controlling weeds in groundnuts. Terbutryn controls the broad-leaved weeds and metolachlor the grasses. They are applied pre-emergence in a mixture of 0.8 + 1.6 kg a.i./ha. A pre-emergence application of metolachlor at 2.0 kg a.i./ha followed by a post-emergence application of bentazon at 1.5 kg a.i./ha about 6–8 weeks after sowing has also been found very effective in controlling weeds in groundnuts.

Harvesting
Harvesting at the right time is very important as it affects both the yield and the quality of the pods. The time of harvesting should be so chosen that a maximum yield of mature pods can be obtained. The right time to harvest the crop may be recognized by a slight yellowing of the foliage and by an examination of the pods. If the pods have begun to shed at the base of the plant and if the inside of the shells has begun to colour brown and show darkened veins, the crop is ready for harvest. When two-thirds of the pods in the field show these signs, irrigation should be stopped and about two weeks allowed for the maturation of the remainder of the crop.

Harvesting too early or too late results in a 30–40% loss in yield. Harvesting too early causes the shrivelling of a large proportion of the kernels. Immature pods lose about one-half of their weight during curing, and they develop undesirable flavours.

The plants are lifted either manually or mechanically. The plants are pulled up by hand in soft soils, and with a hoe or fork in hard and dry soils. The plants are then shaken to free them from soil and stooked to dry out. In mechanical lifting, a tractor-mounted blade cuts the upper roots just below the level of the pods in the soil. A slight tilt of the blade loosens the soil around the plants and makes lifting easier. The plants are then pulled up by hand, or lifted by a special machine. The whole operation can also be done by combine harvester.
The plants then have to be dried so that the pods can be shaken loose from the vines. At the time of pulling, the pods contain 50–55% moisture and they have to be dried to 25% moisture content before they are separated from the vine. The dried pods are separated from the vines either by hand or machine. There are special groundnut harvesters which collect the dried crop directly from the windrow and deliver it to one or more drums which separate the pods.

After harvesting, appreciable quantities of pods are left in the soil. The field can be harrowed and the exposed nuts gleaned by hand. This can also be done by machine.

YIELDS
The average yield per hectare varies in different countries, and ranges from 600–4,000 kg/ha.

STORAGE
Groundnuts stored under unsuitable conditions rapidly become rancid, mouldy or damaged by insects. They should be stored at low temperatures. The lower the storage temperature, the longer will be the storage life. Woodroof (1966) reported that at 21°C, unshelled and shelled groundnuts remained viable and sound for six and four months respectively; at 8°C the respective periods were nine and six months; at 0–2°C, the storage life of shelled nuts might be up to two years. Relative humidity should be below 70%.

CROP PROTECTION
To control diseases and pests, principal reliance should be placed on two preventive measures:

* planting cultivars or strains that exhibit tolerance or resistance to locally prevalent diseases and insects
* practising field sanitation, such as the use of crop rotation and the removal of all plant residues promptly after harvest to reduce the amount of inoculum that might infect new sowings.

DISEASES
Groundnuts are infected by a number of diseases. The major diseases that cause great harm to the crop are leaf spot, stem rot and the virus disease rosette.

Cercospora leaf spot (Cercospora personata and Cercospora arechidicola), also known as tikka, viruela, brown leaf spot, leaf spot, or groundnut cercosporosis, is probably the most serious
groundnut disease on a world-wide scale. Control measures consist of:

* using resistant varieties or strains
* using crop rotation
* removing or burying the debris of the previous crop
* chemical control with sulphur, a mixture of copper and sulphur, or organic fungicides.

**Stem rot** (*Sclerotium rolfsii*), also known as white mould, sclerotium rot, sclerotium blight, sclerotium wilt, root rot or foot rot, has been reported from all over the world. The fungus which causes the disease is particularly prevalent in warmer climates. Control measures consist of:

* using resistant cultivars
* deep ploughing
* burying the old debris in the soil
* the use of slightly raised beds
* avoiding throwing up the soil around the base of the plant during interculture, so that the branches or leaves are not injured or smothered by soil. In this way there will be no weakened or dead plant material to serve as a food base for the fungus.
* the application of pentachloronitrobenzene (PCNB) to the soil before planting (this has given good results in the USA).

**Rosette** is a serious virus disease of groundnuts in many countries. It is characterized by the 'condensation' of the plant. The petioles and internodes are shortened, giving the plant a typical rosette or clumped appearance. The whole plant is severely stunted. Some leaves, especially the younger ones, are more or less chlorotic and faintly mottled. The successive leaves formed after initial infection are smaller, curled and distorted, uniformly yellow, and without green veins.

The virus can be transmitted mechanically or by aphids. It is not seed-borne, nor does it seem to be transmitted by nematodes. In Nigeria, half of the groundnut crop was lost to rosette disease in 1975. Yayock (1976) reported that with the correct cultural practices and the use of high plant populations the disease can be controlled to some extent.

**Nematodes**

Different species of nematodes infect groundnuts and may cause the formation of galls on roots, pegs and pods. Severely infected plants do not develop normally and produce low yields. Rotation with crops that are not attacked by nematodes is the most practical
preventive measure. Fumigation with nematicides is very effective but is also expensive.

**Insect pests**
A large number of insect pests cause damage to groundnuts in the field. Some cause damage regularly, others are only occasional.

**Termites:** there are many species that attack groundnuts. In Nigeria *Amietermes evuncifer* is the most common. The termites cause two kinds of damage. The first is the scarification of the pods. This weakens the shells and makes them liable to shatter or crack during harvest. Breakage results in the loss of kernels, especially with mechanical harvesting. The second type of damage is the penetration and hollowing of the tap root. Sometimes termites reach far into the upper parts of the plant inside the stems. This type of damage may occur during the wet periods of the growing season but pass unnoticed until the plants wilt in a dry period.

Control measures consist of:

* using a uniform cultivar to ensure even ripening and single harvesting
* repeated mechanical cultivation for successive years to reduce the termite population
* the use of lindane dust applied in drills at 1–2.5 kg a.i./ha, or aldrin or dieldrin at 500 g a.i./ha. A seed dressing of aldrin (28.5 g a.i./kg of seed) also gives effective control and is preferable to larger soil applications.

**Leaf-hoppers (Hilda patrueulis):** the plants wilt and collapse due to sap sucking by the hoppers, which are 0.5 cm long and have green and brown markings. The use of dieldrin dust at 1.12 kg a.i./ha before planting is an effective control measure.

**Cutworms (Agrotis ipsilon):** young plants are completely or partially severed at ground level. The developing pods of older plants are also attacked, causing a reduction in yield or the downgrading of the crop. An effective method of control is the use of bait. 450 g of 50% dieldrin wettable powder is well mixed with 50 kg of maize meal which is then wetted until crumbly. This amount of bait is sufficient for 1 ha and should be broadcast in the afternoon to prevent it from drying out before the cutworms emerge to feed (Feakin, 1973).

**Lesser armyworms (Spodoptera exigua):** the plants are defoliated by the larvae which move about in groups searching for further food until they are fully grown. If large numbers of larvae are found they can be controlled by chemicals such as diazinon (300 g/ha), endosulfan (1 kg/ha) or dieldrin (500 g/ha).
African cotton bollworms (*Heliothis armigera*) eat the leaves (particularly the young leaves at the growing point), stems and flowers. The worms may also burrow into the stem near the growing point. Control measures consist of:

* removing the weeds on which *H. armigera* breeds (*Portulaca oleracea* and *Tribulus terrestris*)
* separating the groundnut crop as far as possible in time and space from other hosts of the insect, such as maize and cotton
* the use of endosulfan at 644 ml/ha.
SOYBEANS

(Glycine max (L.) Merr.)

Soybeans are one of the oldest cultivated crops of the temperate regions and one of the world's most important sources of oil and protein. In eastern Asia, mainly in China, the crop has long been used directly for food as a green vegetable, in a wide variety of fermented food products made from the mature beans, and as the edible sprouts of germinating beans. An edible, semi-drying oil is pressed from the mature beans and used for food and cooking, and the remaining protein-rich meal is used as human food or livestock feed.

Origin and Distribution
All available records indicate that China is the centre of origin of the soybean. The cultivar Glycine max is thought to be derived from G. ussuriensis and G. tomentosa, which grow wild in China. The crop has been cultivated in China since prehistoric times and the first record of this crop in China dates back to about 3,000 BC. From China it spread to neighbouring countries such as Mongolia, Korea, Japan and Indonesia. Until recent times, soybeans did not receive much attention, and they are still a minor crop in India, the Middle East, Africa and South America. Soybeans were introduced into Europe in the seventeenth century and into the USA in 1804, but did not receive much attention until the twentieth century. Since 1920 there has been a rapid expansion in soybean production in the USA, and of all the crops produced there since the mid-1960s, none has increased in importance and hectarage as much as soybeans.

Area and Production
The total area and production of soybeans in the world during 1989 were 58 million hectares and 107 million tonnes, respectively. The USA, Brazil, China, Argentina, India, Italy, Paraguay, Indonesia, and Canada are important soybean-producing countries. The total area and production of soybeans in Africa during the same year were 0.4 million hectares and 0.5 million tonnes, respectively. In tropical Africa, important countries for soybean production are Zimbabwe, Nigeria, Zambia, Zaire, Rwanda, Uganda and Ethiopia.

Utilization
The nutritional values of whole soybean seed and soybean meal are given in Table 18.

As a protein food, soybeans are much better than other grain legumes. The protein content of other grain legumes varies from
Table 18 Nutritional values of soybean seed and meal

<table>
<thead>
<tr>
<th>Contents</th>
<th>Whole soybeans (%)</th>
<th>Soybean meal (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protein</td>
<td>39</td>
<td>44</td>
</tr>
<tr>
<td>Oil</td>
<td>18</td>
<td>6.5</td>
</tr>
<tr>
<td>Carbohydrate</td>
<td>25</td>
<td>33</td>
</tr>
<tr>
<td>Ash</td>
<td>4.8</td>
<td>6.0</td>
</tr>
</tbody>
</table>

20–25% while that of soybeans is about 39%. The meal is rich in minerals, particularly calcium, phosphorus and iron. It has good to excellent content of the vitamins thiamin, riboflavin and niacin.

Although soybeans are used as food in China and the Far East, they are not used directly as food in most other countries. The direct use of soybeans as food (i.e. without first fermenting, sprouting or extracting the oil) has certain problems. There are some factors in raw whole soybeans that inhibit or retard protein digestion and other components cause flatulence (the formation of gas in the digestive tract). To denature the inhibitors of digestion and to reduce the tendency to cause flatulence, the beans should be soaked in mildly alkaline water (5 g baking soda per litre of water) for several hours. The soaking water is then discarded and the beans are boiled for 30 minutes in fresh alkaline water. Toasted soybean meal is fully digestible. Soybeans, like any pulse crop, make an excellent green vegetable and the potential inhibitors to digestion are no problem at the immature stages of soybean development.

Soybean flour made from the meal may be mixed with wheat flour (up to 20% soya flour) to produce a wide variety of baked good. It is also used in the making of candies and ice-cream. The seeds are processed to give soya milk (a valuable protein supplement in infant feeding), curds and cheese. Soya sauce, used extensively in cooking and as a sauce in eastern Asia, is made from mature fermented beans.

Soybean oil serves a dual purpose. The bulk of the soybean oil is used for edible purposes, particularly as a cooking and salad oil and for the manufacture of margarine, but the oil is also used industrially in the manufacture of paints, linoleum, oilcloth, printing inks, soaps, insecticides and disinfectants. The meal and soybean protein are used in the manufacture of synthetic fibre (artificial wool), adhesives, textile sizes, waterproofing and fire-fighting foam.

Adaptation
Soybean cultivation now extends from 52°N to the high elevations in the tropics. Soybeans are a warm-season crop and their climatic requirements are about the same as those for maize. For germina-
tion and early plant development, there is need for a moderate moisture supply. The period of germination is the most critical stage and an excess or deficiency of soil moisture at this time could be harmful. Soil temperatures of 15°C or more favour rapid germination and vigorous seedling growth, which is essential for successful competition with weeds. The crop can withstand short periods of drought after the plants are well established. Growing temperatures of between 20 and 25°C appear to be optimum. Soybean seeds produced in higher temperatures (about 32°C) tend to be low in oil quantity and quality. Soybeans are less susceptible to frost injury than maize.

Soybean plants are very sensitive to light duration (photo-period). They are short-day plants, but cultivars differ markedly with respect to the minimum dark period required to induce flowering. Soybeans need high light intensity for vigorous growth and they suffer from shading and competition for light from tall-growing weeds. Self-shading (when grown very close) also affects growth. Soybeans, like cotton, suffer from excessive cloudy weather and are thus adapted to areas that have few cloudy days during the summer months.

Soybeans can be grown on a wide range of soil types, but thrive best on sandy or clay loams and alluvial soils of good fertility. The optimum soil pH ranges from 6.0–6.5. Inoculation is desirable if the crop is taken to a new area. The strain *Rhizobium japonicum*, the nitrogen-fixing bacteria in the root nodules, is specific to soybeans.

**Botanical Description**

The soybean is a herbaceous annual legume. It is usually erect, bushy and rather leafy. Cultivars range in height from 45–120 cm, with growth periods of 75–150 days. It has a tap root which may penetrate the soil as far as 150 cm deep, but most roots are in the top 30–60 cm of the soil. Nodules, when present, are small, spherical and sometimes lobed. Most cultivars have a main stem that branches from the lower nodes. The extent of branching depends on environmental conditions (light and available moisture). The leaves are trifoliate. The stem, leaves and pods are covered with fine tawny or grey pubescence.

The small purple or white flowers are borne on short stalks arising at the nodes of the stems. They are predominantly self-pollinating but cross-pollination by insects does occur, and may be a problem in maintaining cultivar purity in the field. The pistil is simple and the ovary matures into a pod. The pods are small, straight or slightly curved, and range in color from light straw to nearly black. The pods contain one to four seeds, round to elliptical in shape. Popular commercial cultivars have straw-yellow seeds,
but cultivars with greenish-yellow, green, brown or black seeds are also found.

Depending on the cultivar, soybean plants are either determinate or indeterminate in growth habit; earlier-maturing cultivars are indeterminate and later-maturing ones are determinate.

Cultivation

Cropping systems
As a full-season crop, soybeans may be fitted well in the rotations recommended for maize. In alternate years, it may be grown in rotation with maize, sorghum and cotton. In the same year but in a different season, it may be grown as a preceding crop for wheat and potatoes. The continuous cultivation of soybeans in the same field is not recommended since it encourages a build-up of crop pests.

Land preparation
Land preparation for soybeans is similar to that for maize. They need a mellow and firm seed bed, which can be achieved by one ploughing, diskng and harrowing. In soybeans germination is a most critical stage and there should be enough moisture in the soil at the time of sowing. When sown in warm moist soil, germination is rapid and plants emerge from the soil within 3–4 days.

Sowing
The sowing time varies from region to region. The best time for sowing in tropical and subtropical regions is just after the rains are well established, i.e. from the end of May to early July. Soybeans should always be sown in rows. Row spacings vary from as close as 45 cm to as far apart as 100 cm, but spacings of 60–90 cm are most common. Narrower row spacings are preferred nowadays. Regardless of row spacing, 6–12 seeds are sown in 30 cm of row space, although from 4–8 seeds in 30 cm of row space results in essentially the same yield (Chapman and Carter, 1979). With fewer plants per 30 cm of row space, plants tend to branch more prolifically and utilize the extra space, and there is less danger of self-shading.

Seed rates should be based on the desired plant population per hectare and varies from 50–75 kg/ha. With short cultivars, wider row spacings are used, and when sowing is delayed, higher seed rates are required. High seed rates result in taller, sparsely branched plants that tend to lodge easily and set few pods at the lower internodes. Low seed rates favour weed growth, decrease plant height and encourage branching. Wider row spacings and lower seed rates are used in drier areas.

The sowing depth for soybeans ranges from 2.5–5.0 cm. The
emergence of seedlings decreases markedly if the seeds are sown deeper than 5 cm.

**Fertilization**

Soybeans, like groundnuts, have the ability to utilize fertilizer residues that are normally not available to other crops. The plants may excrete special enzymes that break down soil-fertilizer complexes holding essential minerals in a form unavailable to most plants. Regardless of their ability to grow on soils with low fertility, soybeans do remove essential minerals from the soil and these minerals must be replaced.

Soybeans fix atmospheric nitrogen if the right strain of *Rhizobium* bacteria is present in the soil or if the seed is inoculated with *R. japonica*. Nitrogen fertilizer is rarely required for successful production. Soybeans remove large amounts of phosphorus and potassium from the soil. Although precise fertilizer recommendations must be based on the results of soil tests, the application of 40–50 kg P₂O₅ and 60–70 kg K₂O/ha may be recommended to ensure good yields. In some areas, lack of calcium and magnesium may limit crop growth and must therefore be provided. If ordinary superphosphate is used, this will provide the required amount of both calcium and magnesium.

Soybean seedlings are extremely sensitive to fertilizer salts, so banding fertilizer near or with the seed is not recommended. Fertilizers should be worked into the soil by cultivating to a depth of 15–20 cm.

Soybeans are a suitable green manure crop. Even if harvested for seed, soybeans benefit the subsequent crop in a rotation. As a green manure crop, soybeans return as much as 100 kg nitrogen/ha to the soil. If they are harvested for seed, the return is about 18 kg nitrogen/ha.

**Water use**

Soybeans are usually less sensitive to drought during the main period of vegetative growth than during flowering and fruiting. The plants are very sensitive to water stress at the time of flower-bud differentiation and during flowering. Moisture deficits for 2–4 weeks immediately after flower-bud differentiation reduces vegetative growth and causes heavy shedding of flowers and pods. It has been reported that a single irrigation applied at a very late stage of flowering gave a higher yield than when it was applied at the start of flowering.

**Weed control**

In soybean cultivation, the biggest challenge is to have weed-free fields as soybeans do not compete well with weeds in the early
stages of growth. Weed control actually starts with thorough land preparation and using weed-free seed. Because soybeans are sown in relatively widely spaced rows, two hoe weedings till the plants reach a height of 15 cm will be effective in controlling weeds. After the plants are well established they can shade and effectively control newly emerging weeds.

Herbicides can be used as a pre-emergence application or as a combination of pre- and post-emergence applications. Chloramben has been found to be most effective with soybeans and it should be applied pre-emergence. A pre-emergence application of linuron has also been found very effective in controlling weeds in soybeans.

Harvesting and threshing
When soybeans are grown for seed, harvesting is done before the pods shatter. The best stage is when the pods are fully mature with the seeds in the hard-dough stage. The seeds should have a moisture content of less than 15%. In non-shattering cultivars, harvesting is delayed until the crop is fully dried. The plants are either cut at ground level or pulled out of the ground. In the developed countries, most soybean crops are harvested with combines. They are dried for some days and then threshed. The seeds should be stored at a moisture content of 10–12% or less.

Yields
The world average yield is about 1,800 kg/ha. With proper management, it is not difficult to obtain 2,500 kg/ha.

Crop Protection
Diseases
Some of the common diseases that attack soybeans are:

* bacterial blight, caused by *Pseudomonas glycinea*
* bacterial pustules, caused by *Xanthomonas phaseoli* var. *sojense*
* pod and stem blight, caused by *Diaporthe phaseolorum* var. *batatatis*
* wildfire, caused by *Pseudomonas tabaci*
* soybean mosaic virus and yellow bean mosaic virus
* root-knot nematode.

There are three preventive measures that are effective for disease control in soybeans:

* sowing cultivars or strains that are resistant to the prevalent diseases
* good field sanitation
* crop rotation.
**Insect pests**

Soybeans are comparatively free from insect pests. Many pests cause minor damage, but extensive field control is unnecessary. The most harmful insects are grasshoppers, blister beetles, leaf hoppers and velvetbean caterpillars. Most of these pests can be controlled with insecticides.
SESAME
(Sesamum indicum L.)

Sesame is also known as benniseed in West Africa and sim-sim in East Africa. It is the most important tropical crop from which semi-drying vegetable oils are obtained and perhaps the oldest crop cultivated for its oil.

Origin and Distribution
Except for one, which is found in India, all the other 19 wild species of sesame are found in Africa. This suggests that sesame was domesticated in Africa, probably in Ethiopia. The crop spread very early to India, where it came to be cultivated to a much greater extent than in its place of origin. If Africa is the centre of origin of this crop, a secondary centre of diversity developed in India. It is said that sesame was known in Iran at least 4,000 years ago and in Egypt about 3,300 years ago. Sesame appears to have reached China in the first century AD and was taken to the New World about 200 years ago.

Area and Production
Sesame is now grown in the tropical and subtropical regions of Africa, Asia and Latin America. India and China provide almost half of the world production of 2.35 million tonnes of seed per year, whereas Africa produces only 0.59 million tonnes. The major producing countries are: India, China, Myanmar, Bangladesh, the Korea Republic and Turkey in Asia; Sudan, Nigeria, Somalia, Uganda, Ethiopia, Tanzania and the Central African Republic in Africa; and Venezuela, Mexico and Guatemala in the Americas.

In West Africa, sesame is an important crop in Nigeria. It is also grown in northern Ghana, Burkina Faso, Mali and Guinea. In East Africa, it is grown in Uganda and in the less mountainous areas of southern Tanzania.

Utilization
The average nutritional values of the whole seed and the meal after oil extraction are given in Table 19.

The oil contains mainly unsaturated fatty acids (oleic and linoleic, about 40% each) and about 14% saturated acids. It contains no linolenic acid. Sesame meal, produced after oil extraction from dehulled seed, is a very rich source of protein. Both the entire seed and the meal are high in calcium, phosphorus and iron and are well supplied with the vitamins thiamin, riboflavin and niacin.

The whole seed of sesame is used for food, after removal of the
Table 19 Nutritional values of sesame seed and meal

<table>
<thead>
<tr>
<th>Content</th>
<th>Whole seed (%)</th>
<th>Meal (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbohydrate</td>
<td>11</td>
<td>23</td>
</tr>
<tr>
<td>Protein</td>
<td>22</td>
<td>43</td>
</tr>
<tr>
<td>Oil</td>
<td>43</td>
<td>9</td>
</tr>
<tr>
<td>Mineral</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

thin coat (hull) by abrasion. The dried seeds are eaten in soups and, mixed with sugar, are a popular sweet in Africa and Asia. The young leaves are used as a soup vegetable in West Africa. Various parts of the plants are used in traditional medicines in Africa and Asia. The stems are burnt as fuel.

The semi-drying oil is of high quality, odourless and not liable to become rancid. It is used as a salad and cooking oil. The oil is also used in the manufacture of margarine and compound cooking fats. The poorer grades of the oil are used to make soap and paints and as a lubricant and lamp fuel. The oil is also used in some medicinal drugs and perfumes.

Sesame cake produced after the extraction of oil from unhulled seed is an excellent high-protein feed for poultry, ruminants and pigs.

Adaptation
Sesame is mostly grown as a rain-fed crop in the rainy season in the semi-arid regions of the tropics and subtropics. Where the winter is mild, it can also be grown in the winter season. It has high heat and light requirements and is sensitive to low temperatures. Growth and fruiting are favoured by temperatures of around 27°C. It is usually grown in areas with an annual rainfall of 625–1,100 mm. Once established, it can tolerate short periods of drought, but is very intolerant of waterlogging and excessive rainfall. The savanna areas of Africa are well-suited for its cultivation. In East Africa, sesame is grown from sea level to altitudes of 1,500 m. Some cultivars are insensitive to day-length for flowering, while in others flowering is hastened by short days. Sesame is adapted to a wide range of soils, but prefers deep, well-drained, fertile, sandy loam soils.

Botanical Description
Sesame is an erect branched annual, about 1 m tall, covered with glandular hairs. It has a strong tap root and a dense, much-branched lateral root system which spreads in the surface soil. The lower leaves are opposite, broad and palmately lobed, while the upper leaves are alternately arranged, narrow and lanceolate. The flowers
are normally single but sometimes occur in groups of two or three in the axils of the leaves on the upper parts of the stems and branches. The flower are white or pink, with red or purple spots inside the tube. In sesame self-pollination is the rule, but a very small amount of insect cross-pollination also occurs. The fruit is a rectangular, deeply-grooved capsule up to 3 cm long with a short beak. It dehisces by two apical pores through which seed may be lost before or during harvest. A few indehiscent cultivars have been bred. The seeds are about 3 mm long, smooth, flattened and ovate, with white, yellow, red, brown or black testas. Seeds with white testas yield the best-quality oil.

Cultivation

Cropping systems
Sesame occupies the same place as a rain-fed crop in dry regions as does sorghum. It is considered a desirable preceding crop for wheat, as it does not exhaust the soil and improves the soil structure by the loosening effect of its dense root system.

Sesame is rarely grown as a sole crop. In tropical Africa it is usually sown with sorghum, millet or maize. In Uganda it is sown among pigeon peas after the finger millet has been harvested from a mixture of pigeon peas and finger millet. It may also be intersown with maize or sorghum. In the coastal regions of Kenya it is often sown among maize in June shortly before the cereal crop is harvested.

Land preparation
Sesame needs a very fine seed bed because its seeds, being small, produce very weak and slow-growing seedlings. The seed bed should be firm but mellow. This type of seed bed can be prepared only after ploughing the land two or three times and by removing all debris and weeds from the field or burying them in the soil.

Sowing
There is a great variation in the time of sowing in the different countries of tropical Africa. Where the rainy season is of short duration, sesame is sown soon after the establishment of rain and where the rainy season is of longer duration, the crop is sown late in the season so that harvesting can be done after the rains have stopped. Care should also be taken that it is not sown until soil temperatures are about 25°C.

Sowing should always be done in rows. The rows may be spaced about 75 cm apart, and the seed may be sown at rates to ensure one plant every 6–12 cm of row. Under dry-land conditions, inter- and
intra-row spacings should be wider. When sesame is grown as an irrigated crop, row spacing should be closer, i.e. 50–60 cm. The seed rate is normally about 5 kg/ha. Shallow sowing at 2–3 cm depth is recommended.

**Fertilization**

When sesame is grown as a mixed crop with cereals, and if the cereals have been adequately fertilized, there is no need to apply extra fertilizers for the sesame crop. When it is grown as a sole crop, however, it must be fertilized to ensure a good yield. The amount of fertilizer to be applied should be based on soil-test results, but a dose of 50 kg nitrogen, 50 kg $P_2O_5$, and 30 kg $K_2O$/ha may be recommended for most regions. The full dose of nitrogen may be broadcast immediately before sowing. The full dose of $P_2O_5$ and $K_2O$ should be applied in a band by the side and below the seeds. This method of application will minimize the fixation of these nutrients to the soil particles.

**Water use**

Sesame is normally not irrigated but when there is a deficiency of moisture in the soil it is better to irrigate the crop. When irrigation is needed, two to four light irrigations during its growing period will suffice.

**Weed control**

Weeds are a major problem in sesame because in the early stages sesame plants grow very slowly and therefore cannot compete with weeds. All weeds should be removed at a very young stage by hoeing, by cultivating the land with suitable implements, or by using selective herbicides that will kill the weeds without damaging the sesame crop. Monuron, diuron and propachlor have been found to be effective in controlling weeds in sesame.

**Harvesting and threshing**

The time taken to maturity is usually 80–100 days, but some cultivars take 100–140 days to mature. Harvesting should start when the seeds in the lower pods have ripened. At this stage the capsules are still greenish in colour, with a high moisture content, though most of the leaves have turned yellow and have been shed. The stems may be cut near ground level and then bound and stooked in the field to ripen the seed. With dehiscent types, or when harvesting is delayed, it is usually better to cut the heads and dry them in bunches hanging downwards on racks for 1–2 weeks. As they ripen, the seeds fall onto mats placed below the racks. The
heads may also be shaken to dislodge the seeds. Threshing is done by beating with a stick. The indehiscent cultivars may be harvested mechanically.

Yields
The average yield of sesame seed in the world is about 350 kg/ha, but with improved methods of cultivation, yields can be raised to 1,000 kg/ha.

Storage
Before storing the seeds, they should be dried to a moisture content of 10%. The seeds should be fumigated just before they are stored.

Crop Protection

Diseases
The most serious diseases of sesame are:

* bacterial leaf spot, caused by \textit{Pseudomonas sesame}
* leaf spot, caused by the fungus \textit{Cercospora sesame}
* fusarium wilt caused by \textit{Fusarium oxysporum}.

Leaf spot diseases appear at the time of flowering, producing numerous spots on the leaves, which fall off prematurely. The use of disease-free seed and disease-resistant cultivars is the only effective control measure.

In wilt-infected plants, a brown discoloration in the xylem extends gradually from the roots to the apex of the stem. The leaves turn yellow and wither, and eventually the plant dies. The use of disease-free seed and the sowing of resistant cultivars is the most practical control measure.

Insect pests
The principal insect pests of sesame in Africa are the leaf-roller (\textit{Antigastra catalaunalis}) and the sesame gall-fly (\textit{Asphondyla sesami}). These insects may be controlled by spraying with suitable insecticides.
SUNFLOWERS

(*Helianthus annus* L.)

Sunflowers are a relatively new oil-seed crop to most areas of the world, although they have been grown as a major source of oil in the Eastern European countries for about 200 years. At present, sunflowers are the third most important oil-seed crop (following soybeans and groundnuts) in world production.

**Origin and Distribution**

Sunflowers are the only important crop to have evolved within the present confines of the USA. The wild sunflower was an important food plant of the Red Indians of what is now the western United States long before the discovery of the New World. In this area the cultivated variety arose due to selection by man. It was taken to Spain from Central America before the middle of the sixteenth century. The established culture of sunflowers in the United States followed the introduction of improved cultivars that had been developed in Europe before 1600. They were introduced into the USSR in the eighteenth century by Peter the Great and were used for chewing and also as ornament. Sunflowers have now been taken to most countries, both temperate and tropical.

**Area and Production**

Production is much greater in the temperate zones than in the tropics. Production is greatest in the USSR (about a third of world production), Argentina, France, Turkey and Romania. In tropical Africa, sunflowers are produced in Tanzania, Zimbabwe and Zambia. When the total world production of sunflowers in 1989 (21.9 million tonnes) is compared with the average production of 1961–5 (7.3 million tonnes), it is clear that there has been a tremendous increase in production. This increase is partly because of an increase in the area sown from 7.0 million hectares in 1961–5 to 12.3 million hectares in 1989 and partly because of an increase in yield from 1,045 kg/ha in 1961–5 to 1,422 kg/ha in 1989. Africa provides 3.25% of the total world production. The area sown and production in Africa during 1989 were 0.57 million hectares and 0.71 million tonnes, respectively.

**Utilization**

The average nutritional values of the whole seed, dehulled seed and of sunflower meal are given in Table 20.

Sunflower oil is a semi-drying oil containing 44–72% linoleic acid, the amount depending on the conditions under which the crop
Table 26  Nutritional values of sunflower seed

<table>
<thead>
<tr>
<th>Contents</th>
<th>Whole seed (%)</th>
<th>Dehulled seed (%)</th>
<th>Meal (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbohydrate</td>
<td>25</td>
<td>12</td>
<td>36</td>
</tr>
<tr>
<td>Protein</td>
<td>20</td>
<td>24</td>
<td>50</td>
</tr>
<tr>
<td>Oil</td>
<td>46</td>
<td>55</td>
<td>4</td>
</tr>
<tr>
<td>Minerals</td>
<td>4</td>
<td>4</td>
<td>8</td>
</tr>
</tbody>
</table>

is grown. Slow-maturing cultivars and crops grown in cool climates are richest in linoleic acid and have less oleic acid. Sunflower protein is superior to most vegetable protein and equal to soybean protein in terms of digestibility and biological values. 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 groundnut protein 69%. Sunflower seeds and meal are also high in calcium, phosphorus and iron, all essential in the human diet. The contents of the vitamins thiamin, riboflavin and niacin are quite high. The stems and husks are rich in potash.

The seed kernels are eaten raw, roasted or salted. They can also be made into flour. The seeds are used as feed for livestock, poultry and cage birds. The better quality refined oil, which is pale yellow in colour, is used as a salad and cooking oil. The oil is also used in the manufacture of margarine, compound cooking fats and shortening. Being a semi-drying oil, it is used in blends with linseed and other drying oils in paints and varnishes. It is also used as a lubricant and lamp fuel. The cake is a high-protein food for livestock. The hulls, which constitute 35–50% of the seeds, may be used as fillers in feed cakes and meals, as bedding for livestock, and in the preparation of polishing abrasives. After threshing, the heads are fed to livestock. Sunflowers are also grown as fodder and silage for livestock.

Adaptation

Sunflowers can be grown from the equator to 55°N. They are generally considered a warm-season crop. They grow best at medium to high elevations in the tropics, but can also be grown in the lowlands. They are not suited to the wet tropics. Very heavy rain during the early stage of growth or cool wet weather during the ripening stage are not good for the crop.

When the plants are well established they tolerate a considerable amount of drought and heat, with prompt recovery when rain falls. Sunflowers have considerable frost tolerance, and can therefore be grown in climates where occasional low temperatures would seriously damage maize, sorghum and millet.
Sunflowers can be grown on a wide range of soils, but the soil should be deep and well drained. They cannot tolerate very acid or waterlogged soils, but they do tolerate salinity and alkalinity to some extent.

**Botanical Description**
The sunflower belongs to the genus *Helianthus* of the Compositae family. The plant is a herbaceous annual that grows from 0.7–3.5 m tall, usually with only a single, hair-covered erect stem that may be more than 2.5 cm in diameter. It has a tap root system which is well-branched and extends laterally for several metres and can therefore make good use of available moisture and nutrients in the upper soil profile. However, sunflowers do not penetrate and remove water from as deep in the soil as many other tap-rooted crops. The leaves are up to 30 cm long and are borne on petioles arranged alternately on the stem.

The sunflower has a distinctive head of inflorescence. The ray flowers, located around the margin of the head (disc) are sterile; the corollas of these flowers are the petals of the sunflower. The disc flowers located in the central part of the head are fertile (perfect) but incomplete. The discs may vary from 10–30 cm in diameter, depending upon cultivar and plant population. The ovary of the disc flower develops into an achene. The seed is technically an achene fruit consisting of a true seed entirely encased in a fairly rough pericarp. The flowers are almost completely cross-pollinated by insects but under favourable environmental conditions considerable self-pollination may occur.

The sunflower has a peculiar response to light. The plants takes the name 'sunflower' from the bending of its stem towards the sun. In the morning, the head is facing eastward towards the rising sun. During the day, the head (or the stem tissue supporting it) turns so that the head follows the path of the sun. At sunset the head is facing west. During the night the head rotates toward the east and the cycle is repeated. The heliotropic response of the sunflower, a process called nutation, is different from the usual phototropic reaction of plants in that the sunflower anticipates the appearance of the sun. The sunflower ceases its heliotropic behaviour at, or shortly after, anthesis. As a result, as much as 90% of the heads are facing east at maturity.

**Classes of sunflowers**
There are two distinct classes of cultivated sunflowers, an oil-seed class and a confectionery or garden class. Cultivars in the oil-seed class are characterized by smaller and darker seeds of higher oil
content and lower hull content than the cultivars in the confection-
ery class. The hull of the confectionery cultivars is heavier and does
not adhere as tightly to the kernel, thus allowing easy deortication.

**Cultivation**

**Cropping systems**
Sunflowers are a crop of 4–5 months' duration, although some
cultivars have been developed in the USSR which mature in only 70
days. As it is a full-season crop, it can be fitted with all rotations
which are recommended for maize. It is a good preceding crop for
wheat or any other winter crop. It may also be grown as an intercrop
with maize or sorghum.

**Land preparation**
For sunflowers, the land is prepared in the same way as for maize.
All the stubble of the previous crop should be removed and all
growing weeds should be killed and incorporated into the soil. The
larger clods should be broken down and the tilth should be fine,
firm and mellow. There should be enough moisture at the time of
sowing to ensure prompt germination.

**Sowing**
The sowing of sunflowers should be timed so that the crop can fully
utilize the rainfall but mature after the cessation of rain. Thus in
regions with a limited rainy season, such as the Sudan, the Sahel
and the northern savanna regions of tropical Africa, sowing should
be done as soon as the rains begin. In regions with a longer rainy
season, sowing should be delayed to avoid ripening of the crop
during the rainy season.

Seed rates range from 3–5 kg/ha, depending on the size of the seed
and the spacing used. Sowing should be done in rows 60–100 cm
apart and the distance between the plants in the row should be
20–30 cm. Wider or narrowing spacings may be used to adjust to
rainfall expectations. Wider spacings should be used in areas of low
rainfall and narrower spacings in areas of high rainfall. Sowing
should be done 5–8 cm deep, depending on the availability of soil
moisture at the time of sowing.

**Fertilization**
Sunflowers are heavy feeders and their requirement for nitrogen,
phosphorus and potash is high. A dose of 80 kg nitrogen and 50 kg
phosphate/ha can be recommended for this crop. In areas of high
rainfall and also where there is a deficiency of potash in the soil, a
dose of 25–30 kg potash can also be recommended.
The full dose of nitrogen may be broadcast or it may be placed, like the phosphate and potash fertilizers, in bands below and to the side of the seeds. The application of these fertilizers in bands under the seed ensures a nutrient supply to the crop from early germination onward.

**Water use**
To achieve maximum yields, a favourable soil-moisture regime must be maintained throughout the period from the differentiation of the floral organs (when the inflorescence is about 15 mm in diameter) up to harvest. In other words, for about two-thirds of the whole growing period moisture stress must be avoided.

Moisture stress causes reduction in yield and not in oil content.
The reduction in seed yield is mainly due to the reduction in the number of fertile seeds following poor fertilization and the abortion of flowers shortly after fertilization.

**Weed control**
In sunflowers grown at wide spacings, enough room is left for weeds. To avoid competition with the crop plants, the weeds should be uprooted or killed at a very early stage of growth. This can be done with a hand hoe or by intercultivating the field between the rows of crop plants. Selective herbicides can be used either as a pre- or post-emergence application or in combination. A pre-emergence application of prometryne has given good results. Good results have also been claimed for the pre-emergence application of linuron, chloramben and ametryne.

**Harvesting and threshing**
In order to achieve maximum oil production, the heads must be fully mature before harvesting. All the seeds of a head do not mature at the same time, so delaying harvesting until all the seeds have reached full maturity may considerably increase field losses due to shattering, birds and rodents. As a rule, harvesting should start when the backs of the heads have turned yellow and the outer bracts have become brown. Even at this stage, a fair proportion of the seeds may still contain up to 50% moisture, and the seeds will have to be dried. To do this, the harvested heads are placed in thin layers on open drying floors and are turned occasionally when the moisture content is reduced. Large-headed cultivars are frequently cut by hand, but both large- and small-headed types may be harvested by field combine harvesters.

Threshing is done manually by abrasion on a rough or slatted threshing board, or by threshing machine. All chaff and foreign
matter should be winnowed out after threshing. Clean seeds should be further dried to reduce the moisture content to 12%.

Yields
The average yield of sunflower seed in the world is around 1,400 kg/ha, whereas in Africa it is around 900 kg/ha. Yields can be increased with careful management of the crop. More that 3,000 kg seed/ha is obtained in some parts of the world.

Storage
Before storage, the seeds should be thoroughly dried to a moisture level of 10–12% and then fumigated. All storage structures and containers should be cleaned and treated with a suitable insecticide.

Crop Protection

Diseases
Rust caused by *Puccinia helianthi* Schw. is one of the most common and severe diseases of sunflowers. It can reduce yields by 30–50% and can even prevent seed formation. Dark brown rust pustules appear on the underside of the leaves, which turn yellow and in due course dry up and are shed. Growing rust-resistant cultivars is the only control measure.

Other diseases that attack sunflowers are *powdery mildew* (*Erysiphe cichoracearum*) and *stem rot* (*Sclerotinia sclerotiorum*).

Insect pests
Sunflowers are generally not seriously damaged by insects. A few insects that attack the crop are *sunflower maggots* (*Stanzia longipennis*) which tunnel in the stem, *leaf beetles* (*Zygogramma exclamationis*) which feed on the leaves and *moths* (*Homoesoma el electellum*) which attack the seed.

Bird damage
During ripening, sunflowers may suffer from bird damage. Bird damage is frequently more severe when the sunflowers are grown in a small localized area. As a preventive measure, the cultivation of sunflowers near nesting, roosting and water sites should be avoided. As a control measure, harvesting should be done soon after the seeds are filled.
SAFFLOWERS
*(Carthamus tinctorius L.)*

Safflowers are an ancient and important traditional crop of the semi-arid regions of Asia, Africa and the Mediterranean. They were originally grown mainly as a food and dye crop. The flowers were mainly used as a source of dye. At present safflowers are grown almost exclusively as an oil crop.

**Origin and Distribution**
The safflower is most variable in north-east Africa (Nile valley and Ethiopia) and in the Iran-Afghanistan area, where several wild species of *Carthamus* are indigenous. It is believed to have originated either from *C. Oxyacantha* Bieb., which occurs as a weed from Northern India to Turkey, or from *C. lunatus* W., which occurs wild in the Mesopotamian centre of origin of cultivated plants. *C. tinctorius* was cultivated in Egypt in very early times and spread throughout the Mediterranean regions and eastward to China. It was introduced to the New World by the Spaniards, first to Mexico, and from there to the United States in 1925. Safflowers have become an important oil-seed crop only in relatively recent times, and are now cultivated for oil in the semi-arid regions.

**Area and Production**
The total area sown and production of safflowers in the world during 1961–5 were 0.66 million hectares and 0.45 million tonnes respectively, and in 1989 this had increased to 1.26 million hectares and 0.91 million tonnes, respectively, showing an increase of 100% in area and production. In recent years there has been practically no increase in production. Africa accounts for only 3.7% of the total world production. The important countries for safflower production are India, the USA, Mexico, Ethiopia and Australia.

**Utilization**
The oil content of the seed varies from 20–38%; the thinner the hull, the greater the oil content. Safflower oil is a drying oil. It contains 75% linoleic acid and has a low linolenic acid content. Its iodine number is in the range of 140–150. The crude protein content of the expressed meal varies from 20–55%, depending on the amount of hull removed during processing. The meal derived from the dehulled seed averages 42% protein, and the cake derived from the unhulled seed averages 21% protein. Safflower seed contains
18–24% protein. The seeds can be roasted and eaten. The tender shoots of the plant may be used as a pot-herb.

The oil is used as a cooking oil and in the manufacture of margarine. It is also used in the manufacture of soaps, paints and varnishes. The meal is high in protein and is a valuable livestock feed supplement. The cake left after extracting oil from undecorticated seed is used as a fertilizer.

**Adaptation**

Safflowers are a rain-fed crop of the semi-arid regions of the tropics and subtropics. The plants are very drought-resistant and make very effective use of available soil moisture because of their very deep roots. It is the most drought-tolerant of the oil-seed crops, although it does require a high soil-moisture content for germination and early growth. High soil water content is conducive to root rots, to which safflowers are very susceptible. Waterlogging causes a high mortality rate. Safflowers are adapted to deep, average to fertile soils with a high water-holding capacity and a neutral pH. Good drainage is essential.

**Botanical Description**

The safflower is a member of the thistle, or composite, family, Compositae. It is an annual with stems ranging from 60–150 cm in height. The stems branch prolifically near the top and are determinate in growth habit. The leaves are sessile (without petioles) and toothed along their margins. The leaves and the bracts below the flowers have short spines. Each stem terminates in a typical head of inflorescence, varying in size from 1.3–3.5 cm in diameter. The flowers may be white, yellow, orange or red. The fruit is a smooth, shiny white achene, very angular, nearly wedge-shaped and less than 1.3 cm in length.

**Cultivation**

*Cropping systems*

Safflowers are generally sown almost at the end of the rainy season, and make their growth on stored soil moisture. Because they thoroughly exhaust soil moisture to a great depth, they may have a depressing effect on the next crop grown during winter in the semi-arid regions. No crop is therefore sown soon after safflowers. Because of their deep and extensive root system, however, safflowers leave the soil in an improved physical condition and under irrigation can prove a good preceding crop.
Land preparation
Safflowers are a crop to which the principle of minimum tillage can be applied. Being a deep-rooted crop, it does well even in a rough seed bed and one or two ploughings are sufficient.

Sowing
Seeds should be sown in rows 70–90 cm apart, and 10–15 cm apart in the row. This requires about 20–25 kg of seed/ha. The sowing depth varies from 2.5–5.0 cm and the seed should be sown into moist soil.

Fertilization
Safflowers respond to fertilizers. For rain-fed culture, an application of 25–40 kg N and 30–45 kg P₂O₅/ha is recommended. For an irrigated crop, the dose of nitrogen can be doubled. The fertilizers should be applied in a band below and to the side of the seeds.

Weed control
The early growth of safflowers, when the plants are in the rosette stage, is very slow and weeds are a problem at this stage. Weeds should be removed or killed in the very early stage, either manually, mechanically, or by using selective herbicides. The use of a rotary hoe cross-wise when the safflower plants are 10–15 cm high is the most effective and cheapest method of weed control. A pre-planting or pre-emergence application of Propham can also be used to control weeds.

Harvesting and threshing
Safflowers mature in about 120 days. Good features of the crop are that it does not lodge or shatter and is not subject to bird damage, so harvesting presents no problem. When grown for oil, the plants are harvested when they are fully ripe, i.e., when the moisture content of the seeds is down to the 10% required for safe storage. Threshing is done by machine or by hand, although hand threshing is quite troublesome because of the spines.

Yields
The average yield of safflowers in the world is about 700 kg/ha, and in Africa it is about 500 kg/ha. There is great scope for increasing the per hectare yield of the crop.

Storage
Before storage, safflower seeds should be dried to a moisture content not higher than 10%. The seeds should also be fumigated just before storage.
Crop Protection

Diseases
The important diseases that attack the safflower crop are root rot, caused by Phytophthora drechsleri, rust, caused by Puccinia curthami and stem rot, caused by Sclerotinia sclerotiorum.

Insect pests
Safflower is not very prone to damage by insect pests. The only serious pest is the larva of Acanthiophilus helianthi.
CASTOR  
*(Ricinus communis L.)*

Like sesame, castor is an ancient oil crop of early Mediterranean civilization. Castor oil is non-drying and in earlier times was an important lamp fuel. Castor is also an important medicinal plant.

Origin and Distribution
Castor belongs to the family Euphorbiaceae. It grows wild in Africa, Asia and the Americas. It probably originated in Ethiopia, or at least in north-east Africa. The plant has been domesticated since ancient times and was found in Egypt as long ago as 4,000 BC. It was taken to India and then to China before recorded history. It was introduced into the New World shortly after this was discovered. The castor plant is now naturalized in many tropical and subtropical countries.

Area and Production
The demand for castor seed and oil has increased greatly in recent years. The average production during 1961–5 was 0.68 million tonnes and in 1989 it rose to 1.15 million tonnes. Africa accounts for about 3.6% of the total world production. There has been a decline in production in Africa from 62,000 tonnes during 1961–5 to 42,000 tonnes during 1989.

Important countries for castor production are China, India, Brazil, the USSR and Paraguay. In tropical Africa, castor is produced in Ethiopia, Sudan, Tanzania, Kenya, Angola, Madagascar, Benin, Mozambique and Uganda.

Utilization
Castor seeds contain 40–55% non-drying oil. The small-seeded cultivars have more oil than the large-seeded ones. The iodine number of castor oil is about 85. The oil consists of up to 90% ricinoleic acid. The seed contains enough of the albuminoid toxin ricin to cause serious illness or death if even only one seed is eaten. The seed also contains a powerful allergen, a protein polysaccharide by nature. Neither the ricin nor the allergen is carried over into the oil if it is properly extracted, but remains in the meal (cake). The cake cannot be fed to livestock unless it is treated to render the ricin and allergen harmless.

Up to the beginning of the twentieth century, the main use of castor oil in the western world was in medicine, mainly as a purgative. In many parts of Africa, the seeds of castor are crushed, fermented, and used as a seasoning in soups and stews. Now the bulk of the crop is utilized in industry. The oil is a non-drying type and
has chemical properties which makes dehydration possible. On dehydration, a drying oil is produced, which does not turn yellow on drying or baking, hence its value in paints and varnishes. It has a constant viscosity at high temperatures and is thus useful as a lubricant for machinery. Modified castor oil is used in paints and varnishes to increase their quick-drying property. Castor oil and its derivatives have many industrial uses. It is used in the manufacture of hydraulic fluids, plastics, certain explosives, electrical insulations, ointments, cosmetics, nylon and other synthetic fibres, and purgatives.

The meal is detoxified and used as livestock feed. The castor cake (pomace) averages 5.4% nitrogen, 1.8% phosphate and 1.0% potassium, and is crushed for use as a fertilizer. The dried stems can be made into paper and wall-board and are also used as fuel.

Adaptation
Castor grows over a wide range of climatic conditions but prefers drier climates. Castor produces well in subhumid to moderately-humid regions, and under irrigation in arid regions. In very humid regions the plants are affected by moulds that destroy the flower clusters. The plants are killed by frost and damaged by heavy rainfall and waterlogging. Castor is most common where the temperatures during the growing season are 20–30°C and set is poor in temperatures higher than 40°C. The best soils for its cultivation are rich, well-drained sandy or clay loams, but it grows well on many other deep soils.

Botanical Description
Castor is a short-lived perennial in the tropics and subtropics, but it is usually treated as an annual crop. The height of the plant varies from 1–6 m but annual cultivars grow up to only 2 m. The plant has a well-developed tap root which normally extends to a great depth. The leaves are large, 10–30 cm wide, and vary in colour from green to purplish or reddish.

The greenish-yellow flowers have no petals, and are borne in clusters. Blooming is indeterminate and new clusters and ripe seeds occur on the same plant. The inflorescence is a panicle with female flowers at the top and male flowers at the bottom. As the female flowers open before the male, there is a high degree of cross-pollination. Each female flower produces a thick-walled spiny capsule with three loculi, each loculus containing one seed. The seed is ovoid, shining, pale grey to almost black with darker mottlings. There is a yellowish-white caruncle at the base of the seed. The seed varies in length from 0.5–1.5 cm.
Cultivation

Cropping systems
Castor has a favourable effect on the crop that follows because it improves soil tilth. When castor is grown as a sole crop, it can be fitted in well in rotation with any summer crop such as sorghum or maize. Castor is frequently sown in mixtures of varying proportions with sorghum, maize, cotton and groundnuts. It is a crop which can be grown on stored soil moisture.

Land preparation
A thorough preparation of the land is not essential because the castor seed is big and vigorous.

Sowing
Castor is mostly sown towards the middle of the rainy season. Sowing is done in rows spaced 70–100 cm apart, and 25–30 cm within the row. Castor seeds require more moisture for germination, and for a longer period, than many other crops. Sowing should therefore be done when there is enough moisture in the soil and the seeds should be sown at a greater depth than is usual for other crops. Sowing depths of up to 6–8 cm will have no adverse effect on emergence.

Fertilization
The nutrient requirement of castor is rather high and a dose of 30–40 kg nitrogen, 40–50 kg P₂O₅ and 40 kg K₂O (if needed) per hectare may be applied. It is advisable to apply the fertilizers in a band near the seeds.

Water use
As castor is sown in the middle of the rainy season, there is normally no need for irrigation in the early part of the growing season. However, irrigation may be needed later on in the season. Where castor is grown with irrigation facilities, the first irrigation is given when the plants are in the 6–8 leaf stage. From then on, 4–6 irrigations are given until 2–4 weeks before harvest.

Weed control
Castor plants emerge very slowly, usually 2–3 weeks after sowing, and it is only after the middle of the growing season that they provide a canopy. Weeds therefore get an ample chance to grow in a castor field. Weeds should be removed or killed either mechanically or with selective herbicides. Promising results have been obtained
with pre-emergence applications of chlorthal, prometryne, chloramben or trifluralin.

_Harvesting and threshing_
To avoid losses due to shattering, castor should be harvested before the seeds reach full maturity. Harvesting can be either manual or mechanical. Manual harvesting has the advantage that in the first harvest only the ripe clusters are harvested; the remaining clusters are harvested after some days when they have ripened. Manual harvesting is completed in 2–3 pickings.

Threshing is very easy as it requires little beating to separate the seeds.

_Yields_
The world average yield of castor is about 750 kg/ha. In the USA, a yield of about 3,000 kg/ha is obtained. The average yield of castor in Africa is about 500 kg/ha.

_Crop Protection_

_Diseases_
Diseases are not a serious problem in dry areas, but are serious in regions of high rainfall. The important diseases of castor are bacterial leaf spot, caused by _Xanthosomonas ricanicola_ and cotton root rot, caused by _Phytmotrichum omnivorum._

_Insects pests_
The caterpillars of _Arhaea janata_ and _Diochocrosis punctiferalis_ are of some significance to the castor crop.
All the oil-seed crops that have been described so far in this chapter are annual field crops. The oil palm is not a field crop but a tree which comes into fruit 4–6 years after transplanting, and may continue to bear fruit for 50 years. It has been an important source of oil in tropical West Africa. Oil palms give a higher yield of oil per unit area than any other crop. Two distinct types of oil, namely palm oil and palm kernel oil, are produced. Both of these are industrially important. Palm oil is obtained from the fleshy, orange mesocarp of the fruit which contains 45–55% oil; and palm kernel oil is obtained from the kernel or endosperm (after it has been removed from the stony endocarp) which contains about 50% oil.

**Origin and Distribution**

The oil palm is a native to the humid tropics of West Africa. It occurs wild along the banks of rivers and streams in the transition zone between rain forest and open savanna. The depth of the oil palm belt varies from a few kilometres to 80 kilometres or more. In such regions, oil palms are often the predominant trees and in some limited areas (as in eastern Nigeria) wild oil palms in the forest may be so dense as to give the impression of a deliberate plantation. Oil palms extend east across the central rain forest belt between latitudes 3°N and 7°S, as far as the borders of Zaire and Uganda. They also occur in scattered locations in East Africa and Madagascar.

From West Africa, oil palms were introduced to South America at the time of the slave trade, and became established in Brazil. Later they were taken from Africa to Malaysia, Indonesia and Singapore, where they are now cultivated on a very large scale.

**Area and Production**

In 1989, the total production of palm oil in the world and in Africa was 10.17 and 1.56 million tonnes, respectively. In the same year the total production of palm kernels in the world and in Africa was 3.01 and 0.83 million tonnes, respectively. Malaysia alone accounts for about 60% of world palm oil production. Other important countries for the production of palm oil are Indonesia, Nigeria, Colombia, China, Zaire, Thailand, Côte d'Ivoire, Papua New Guinea, Ecuador, Cameroon, Ghana, Brazil, the Philippines, Guinea, Sierra Leone, Angola, Benin, Liberia, Peru, Congo and Togo.
Utilization
Palm oil is pressed from the mesocarp, usually in the countries where the trees are grown. It varies in colour from pale yellow to deep orange. The oil is a rich source of carotene, a precursor of vitamin A. The darker-coloured oils have the highest carotene content, with up to 1,000 or more ppm. The mesocarp contains 50–65% oil with iodine numbers in the range of 44–58. The best quality palm oil has a free fatty acid (FFA) content of around 3.5%. Poor quality oil obtained by using traditional methods may contain as much as 85% FFA. The palm oil is solid at ambient temperatures in the tropics, ranging in consistency from that of soft butter to a hard, tallow-like substance, depending on the method used to extract it from the fruit. Palm oil is being increasingly used for edible purposes, including the manufacture of margarine and compound cooking fats. In industry, palm oil is used principally in the manufacture of soap, lubricating oils and candles, and in the tin plate and sheet steel industries.

Palm kernel oil is obtained from the seed (the kernel or endosperm) which contains about 50% oil. It is white or pale yellow with iodine numbers in the range of 14–22. It has a high proportion of saturated acids. It is a hard oil, closely resembling coconut oil, with which it is readily interchangeable. It is used as cooking oil or edible fat, in the confectionery and bakery trade, and also in the manufacture of toilet soaps, soap powders and detergents. In West Africa it is used as hair oil and skin lotion, and is often mixed with imported scents. Mixed with kerosene, it is used as a furniture polish, and sometimes also in traditional medicine.

When the oil has been extracted, the residue (palm kernel cake) is rich in carbohydrate (48%) and protein (19%), and is used as cattle feed. The ash remaining when the bunch refuse is burnt is rich in potash and is used to make soap.

Palm wine is produced from the sap obtained by tapping the male inflorescence. The fresh sap is sweet, as it contains about 4.3 g/100 ml sucrose and 3.4 g/100 ml glucose. It ferments quickly to produce a more piquant drink. The drink has a milky flocculant appearance, caused mainly by suspended yeast cell, and a slightly sulphurous odour. It is an important source of the B vitamins in the diet of those who drink it.

In West Africa the leaves are used for thatching and the petioles and rachises are used for fencing and protecting the tops of mud walls.

Adaptation
In its natural habitat, the oil palm occurs wild in riverine forests. It does not flourish in natural forests unless these have been cleared by
man. Oil palms requires adequate light and soil moisture. These requirements for light and water confine commercial plantations to areas cleared of rain forest. Oil palms can tolerate temporary flooding, provided the water is not stagnant.

Oil palms flourish well in areas with an annual rainfall averaging 2,000 mm or more distributed evenly throughout the year. Areas with high rainfall but with a marked dry season lasting 2–4 months are not very suitable for oil palms.

A high level of solar radiation is important for growth and bunch production. At least five hours of sunshine per day in all months of the year is desirable. A mean maximum of 30–32°C and a mean minimum of 21–24°C are the most suitable temperatures. Seedling growth is arrested at temperatures below 15°C.

For oil palms, the water-holding capacity of the soil is more important that the fertility. They can be grown on a wide range of tropical soils, but waterlogged and very sandy, stony or peaty soils should be avoided. Oil palms can be grown on soils with a wide range of pH, and many of the soils used for the crop have a pH of 4–6.

**Botanical Description**
The oil palm is a member of the subfamily Coccoideae of the family Palmae. It is an erect, unbranched tree up to 30 m tall with a stout trunk covered with persistent leaf bases (Figs 62, 63).
Adventitious primary roots grow from the base of the stem, the bole, and from its aerial parts up to 1 m above the soil. Their length depends upon the water table. They remain short when the water table is high. A few primary roots, 8–10 cm in diameter, penetrate deeply to anchor the plant, but most of them grow horizontally in the top 1 m of the soil, and as far as 20 m away from the bole. From these primaries, many secondary roots, 2–4 cm in diameter, are produced. They mostly remain in the top 15 cm of the soil and branch freely to produce a dense mat of roots.

The diameter of the stem varies from 22–75 cm. Leaf bases adhere to the stem for at least 12 years and sometimes longer. The stem terminates in a crown of leaves at the very top of the plant; 70–100 leaves are produced in spiral succession from the apical meristem. Each leaf elongates up to 7.5 m, of which the petiole forms about a
quarter of the length. The petiole is massive with a broad base clasping the stem. Small, sharp spines are closely crowded along both sides of the base of the petiole.

Flowering begins when the young palm has become well established, i.e. when it is 4–6 years old. The inflorescences are compound spikes, one borne in the axil of each leaf. Each inflorescence develops in the apical bud for two years and a further 9–10 months are required to flowering and anthesis. The oil palm is monoecious so that male and female flowers occur separately. The male and female inflorescences do not appear on the plant at the same time; periods of production of male flowers alternate with periods of production of female flowers. Cross-pollination therefore almost always occurs.

The male inflorescence has a short, stout peduncle which supports a cylindrical mass of brown spikes, each with as many as 700–1,200 packed small male flowers, sunk in tissues of rachis. The female inflorescence reaches a length of 30 cm before opening. The peduncle of the female inflorescence is shorter and stouter than that
of the male. Female flowers are arranged spirally in shallow cavities on the racis, with 20–30 flowers.

After fertilization, the female inflorescence develops into the fruit bunch. Each bunch may contain about 200 fruits. A single bunch may weigh 18–25 kg, of which 60–65% consists of fruits. The fruits mature 5–9 months after flowering; they are fibrous drupes about 4 cm long and 2 cm broad, with a pointed apex (Fig. 64).

The drupes have a leathery, fairly thin exocarp surrounding the fleshy mesocarp (which constitutes 35–95% of the weight of the fruit), a hard endocarp and a seed (Fig. 65). Much of this variation is associated with variations in the thickness of the endocarp.

**Cultivation**

**Propagation**

Oil palms are propagated from seed. The seeds germinate very slowly and to hasten germination, the moistened seeds are mixed with charcoal and put into small boxes and then into polythene bags. These are laid on crossbars or wire netting in the oven of a germinator. In rural areas, the germinator is usually a packed earth building with an opening underneath at the back, where a fire is lit. The temperature of the germinator is raised to 38–40°C, and must not be allowed to rise higher. Another method is to put the seeds into the trays without bags, and to water them every three days. A wet sack on the floor helps to keep the atmosphere damp so that the seeds will germinate. About 80% of fresh seeds and 50–60% of stored seeds will germinate. Not all the seeds germinate at the same time. Each week the germinated seeds are removed from the polythene bags and the rest moistened again and put back. The thin-shelled tenera seeds germinate more quickly than the thicker dura seeds (tenera, dura and pisifera are the three groups of oil palm).

**Pre-nursery**

The germinated seeds are fragile and are therefore first planted in prepared beds, trays, baskets or bags before being transferred to the
field nursery. Soil for the pre-nursery should be well-drained, fertile topsoil. The beds should be 20–23 cm high and not more than 1.2 m wide. A convenient size for trays is 120 × 69 cm and 15–20 cm deep. The sprouted seeds are planted carefully at distances of 7.5 × 7.5 cm, their delicate roots pointing downwards, and covered with 2.5 cm of soil. The baskets should be 23 cm deep and 10 cm in diameter, but black polythene bags, 23 × 15 cm, are now commonly used. Polythene bags are particularly useful when the seedlings have to be transported some distance to the nurseries. The pre-nursery need not be shaded provided adequate water is available.

**Nursery**
After 4–5 months, when the seedlings reach the 4–5 leaf stage, they are transferred to field nurseries or large polythene bags where they grow for 6–12 months before being transplanted to the field. The nurseries should be on a flat area near a source of water. The soil should be well-drained, friable and fertile. Very fine nursery soils are prepared by deep ploughing and removing all the debris from the field. Organic manure should be incorporated in the soil before planting.

The seedlings, with a good ball of earth around their roots, are then planted in the nursery at a distance of 75–90 cm apart. It is not necessary to shade the nursery. Watering is required in the early stages and later during dry periods.

**Transplanting in the field**
Great care should be taken when uprooting (lifting) the seedling from the nursery. It is essential that the seedlings to be transplanted should have a substantial ball of earth (35–45 cm in diameter) around their roots. It is not advisable to transplant seedlings younger than 10 months or older than 20 months. When planting with a ball of earth is impracticable, bare-root planting may be necessary. In this method the roots are dipped in clay slurry as soon as they are lifted. With seedlings 12–18 months old, some leaf pruning may be necessary to reduce the seedlings to a height of 1.2 m.

The optimum density of planting in the field is about 150 palms to a hectare. This can be obtained by a triangular spacing of 8.8 m between palms and 7.6 m between rows. Higher densities give high early yields but in later years give lower yields. The area around the planting holes should be cleared of all vegetation to a radius of 1 m. In West Africa, young palms should be transplanted at the beginning of the rains, though in Malaysia it is done all year round. Ammonium sulphate and muriate of potash, each at the rate of 230 g per palm, may be applied in a ring around the seedling at planting.
Where there is danger from rodents, the transplants should be protected by a wire collar.

**Intercropping**

On smallholdings oil palms are usually intercropped with food crops such as maize, cassava, yams, cocoyams or bananas. This can be done for up to three years. On large plantations, cover crops (a mixture of legumes and grasses) are often planted.

**Fertilization**

Oil palm fruit bunches remove certain nutrients from the soil in high quantities and few soils can support optimum growth and yield unless adequately fertilized. The recommendation for Nigeria, which is applicable for most of West Africa, is as follows:

* in the nursery apply 114 g of a mixture of N, P₂O₅, K₂O and Mg in the ratio 1:1:1:2, per seedling
* in the field at transplanting apply 15 kg N, 24 kg K₂O and 4 kg Mg per hectare
* in the first year after transplanting apply 15 kg N, 45 kg K₂O and 7 kg Mg per hectare
* in the second year after transplanting apply 30 kg N, 60 kg K₂O and 10 kg Mg per hectare
* in all subsequent years apply 30 kg N, 75 kg K₂O and 17 kg Mg per hectare.

In the nursery, the fertilizers should be properly mixed and divided into two equal lots to be applied at two and eight months after seeding. The fertilizer is spread in a ring 7.5–15 cm from the seedling. Each seedling should receive 114 g of the mixture.

In the field, the fertilizers are mixed and spread in a ring around the base of the oil palm up to a radius of 1.5 m. The ring should be completely free of weeds. During the year of transplanting, half the N and all of the K₂O and Mg should be applied 6 weeks after transplanting and the balance of N should be applied 5–6 months after transplanting. For all other years, all the fertilizers should be applied at the same time in April or May before the rain becomes too heavy and frequent.

**Weed control**

Intercropping oil palms during the establishment stage is a useful means of controlling weeds as well as being a source of income before the trees begin to yield.

Of the herbicides, the usual triazine and urea herbicides (atrazine, simazine, diuron and monuron) are quite safe and can be recommended. Simazine appears to be outstandingly safe. Where weeds are present at the time of spraying simazine, it is better to add
paraquat, dalapon or amitrole to the simazine to increase the contact effect, but extra care must then be taken to keep the spray off the crop. The margin of safety with dalapon on young palms appears to be small (Kassasian, 1971).

**Harvest**

The oil palm begins to bear fruit 3–4 years after transplanting. It is generally not economical to harvest the first fruit. Fruiting may continue for 50 years. Most bunches appear at the time of the first rain, and the remainder from time to time throughout the year. Bunches form 5–6 months after pollination. Under-ripe fruits have a low oil content and over-ripe fruits produce oil with a high fatty acid content. Bunches should be harvested at the correct stage of ripening, i.e. when the first ripe nuts begin to fall to the ground. Usually only one bunch on a tree ripens at a time. The ripe bunches should be cut very carefully so that the subtending leaf is not cut. Harvesting becomes difficult and uneconomic when the tree becomes too tall.

**Processing**

Soon after harvesting, the fruits are separated from the bunch by loosening the fruits. In the natural course of things, this may take a week, and by that time there will be a considerable increase in the free fatty acid content, with a resultant lowering in quality. Rapid extraction of fruits from the bunch and sterilization of the bunch are therefore important. Indigenous methods of extraction in West Africa are crude, resulting in poor quality oil. In the soft-oil process used in eastern Nigeria the oil extraction rate is 6–10% with a FFA content of 7–12%. In the hard-oil process as used in the Niger delta, the oil extraction rate is 4–6% with a FFA content of 30–35%. In Nigeria, a good quality oil having less than 3% FFA is obtained with the hydraulic hand press. In Malaysia, large power-operated mills are used. In these mills, the oil extraction rate is about 18% of fruit and 4% of palm kernels, and the oil has a FFA content of less than 3%. The essential features of these oil mills are standardized and they perform the following operations:

* sterilization of the bunches
* stripping of the bunches
* digestion and mashing of the fruit
* extraction of the mesocarp oil
* clarification of the palm oil
* separation of the fibre from the nuts
* nut drying
* nut grading and cracking
* kernel separation and discarding of the shell
* kernel drying and bagging.
A good quality oil should have a FFA content of less than 3%, a water content of less than 0.1% and a dirt content as low as 0.005%, the oil should be easily bleachable.

Yields
Young oil palms produce a large number of small bunches, but bunch weight increases at a rapid rate with age, and full mature yields are usually reached 6–8 years after coming into bearing. Yields from semi-wild palms in West Africa range from 1.2–5 tonnes of bunches per hectare per annum. Estate yields in Africa and in the Far East vary from 7.5–15 and 15–25 tonnes of bunches per annum, respectively. Estate palm oil extraction rates for different types vary from 15–22%, giving a yield of oil well over 5 tonnes per hectare per annum. The extraction rate from kernels varies from 3.5–5% or more.

A mean annual yield of 4,000 litres per hectare of palm wine from 150 palms has been recorded in eastern Nigeria and was estimated to have a value more than double that of the oil and kernels from similar palms (Purseglove, 1972).

Crop Protection

Diseases
The principal diseases of oil palms are blast, freckle and anthracnose.

Blast, caused by Pythium splendens and Rhiisoctonia lamellifera is a root disease causing the wilting and sudden death of nursery seedlings. It is most severe during the early part of the dry season. There is no effective control for the disease, but keeping the seedlings adequately watered all the time can reduce its incidence.

Freckle, Carpospora elaeidis, is a serious disease of the nursery stage in West Africa. Brown spots appear on the leaves, and the affected portions die. It can be controlled by spraying with Dithane M-45 (mancozeb) or captan.

Anthracnose, Batryodiplodia palmrarum, attacks pre-nursery seedlings and newly planted nursery seedlings. It causes brown areas to appear on the leaves. The leaves may die and the entire plant becomes extremely weak. One control measure is to avoid overcrowding in the nursery. The disease can also be controlled by spraying with Dithane M-45 or captan.

Insect pests
The main insects pests of oil palms are palm weevils (Rhynchophorus phoenicis and Orceyes owariensis), leaf miners (Coelopaenomenodera elaeidis) and slug caterpillars (Parasa viridissima). These pest may be controlled by using suitable insecticides.
Other pests
Many rodents, including rats, cutting grass (*Thryonomus swinderianus*) and porcupines, damage the seedlings and fruiting palms. They can be controlled by using rodenticides. Wild pigs and elephants can also cause extensive damage. The palm-nut vulture (*Gypohierax angolensis*) causes some damage in palm groves in Africa.
14

FIBRE CROPS

Before the advent of synthetic fibres, vegetable fibres and wool were the only materials available for making cloth. In the last 200 years vegetable fibres have occupied an important position among the world's crops and they have become a valuable commodity for world trade. The vegetable fibres are not only important for textiles; many other valuable products are made from them. Some of them have not remained only fibre crops but have become important sources of vegetable oils used for food and industrial purposes.

Vegetable fibres are classified into three groups according to their anatomical origin in the plant:

* surface hairs: associated with the fruits and seeds of plants; these are single-celled outgrowths from the testa or from the ovary wall, which protect developing seeds. Cotton (Gossypium spp.) is the only crop belonging to this group which produces lint. Another is a tree (Ceiba pentandra) which produces kapok. This consists of single-celled, lustrous hairs with a waxy coating which grow from the ovary wall.

* phloem, bast or soft fibres: these are the schlerenchyma fibres associated with the phloem of the stems of plants. These fibres are a constituent of the bark which is stripped from the stems. The fibres occur in bundles of up to 700 individual cells. Although many plants contain phloem fibres, the following are the species from which the fibres can be extracted easily:
  * jute (Corchorus capsularis and C. olitorius)
  * flax or linseed (Linum usitatissimum)
  * kenaf (Hibiscus cannabinus)
  * roselle (Hibiscus sabdariffa)
  * sunhemp or deccan hemp (Crotalaria juncea)
  * hemp (Cannabis sativa, C. indica)
  * ramie (Boehmeria nivea)
  * aramina or Congo jute (Urena lobata).
* leaf, structural or hard fibres: these are bundles of sclerenchyma fibres which occur in the leaves. Important plants of this group are:
  * sisal (Agave sisalana)
  * henequen (Agave fourcroydes)
  * abaca or Manila hemp (Musa textilis)
  * New Zealand hemp (Phormium tenax)
  * Mauritius hemp (Furcraea gigantea)
  * bow-string hemp (Sansevieria spp.)
* palm fibres: many palms of the tropics are used. Coir fibre is obtained from the mesocarp of the coconut fruit.

From the trade point of view, the vegetable fibre crops listed above are divided into textile fibres, cordage fibres and coir fibre. The textile fibres are mostly soft and comprise the crops grown for surface-hair fibres and for phloem fibres. The cordage fibres are coarse and hard and comprise the crops grown for leaf, structural or hard fibres. These are used mainly in the manufacture of ropes, cables and twines. Coir fibre is used to make brushes, mats, coarse yarn, and to stuff upholstery.
COTTON
(Gossypium spp.)

Cotton is the most important of the vegetable fibres. It is used for many purposes but especially to make the textiles used in the manufacture of a large proportion of man's clothing, especially in the tropics where the environment demands the lightest possible absorbent fabric for clothing. Cotton is virtually a crop of the twentieth century in sub-Saharan Africa, whereas in India, Egypt and the USA it was a crop of major economic importance during the nineteenth century.

In early times, cotton was the principal fabric in India, silk and ramie in China, flax in Egypt, hemp in northern Europe and wool in western and southern Europe. At the end of the eighteenth century, cotton provided only 4% of the world's raw textiles, compared with 78% for wool. By 1890, cotton provided 78.6% of the world's textiles, increasing to 84.2% in the period 1924–28 (Purseglove, 1972). Since then the percentage has decreased somewhat due to competition from synthetic fibres but the increasing world demand for fibres of all kinds in recent years has ensured that vegetable fibre production has also increased.

Origin and Distribution
The origin of the different species of Gossypium has been a subject of considerable controversy. The various species have originated in different centres. The wild lintless diploid species probably evolved in southern Africa, and spread from there to the arid regions of Arabia, south-east Asia, Australia and America.

So far 31 species of cotton have been recognized, out of which only four species are cultivated: two diploid species, G. herbaceum and G. arboeum of the Old World, and two tetraploid species, G. barbadense and G. hirsutum, of the New World.

Old World cotton
The wild species which is cytogenetically closest to the cultivated species of G. herbaceum and G. arboeum, is G. anomalum which is found exclusively in Africa. In South Africa a wild cotton occurs, G. herbaceum var. africanum, which is perhaps the transitional species between the wild ancestors with G. anomalum and the cultivated species G. herbaceum. Following certain genetic changes in G. herbaceum, another closely related cultivated species arose, namely G. arboeum.

India appears to have been the main cotton-producing area of the Old World; from there the two species spread along the commercial
routes radiating around the Indian Ocean, reaching the countries of
the Far East in one direction, and northwards through East Africa to
Egypt and the Mediterranean in the other direction. The trade routes
(both land and sea) developed by Alexander the Great introduced
the textiles of India to Europe and the West. Just when and how
cotton became a crop in Arabia and Syria is not clear. The Saracens
and Moors brought the plant to Spain in the tenth century. After the
opening of the sea route to India by Vasco da Gama, cotton textiles
spread to Europe.

**New World cotton**

Two centres of variability (centres of origin) exist for the two New
World cottons: *G. hirsutum* in southern Mexico and Guatemala, and
*G. barbadense* in northern Peru (Elliot *et al.*, 1968). Long before the
colonial period, spinnable cottons had become widely spread by the
native Indians throughout most of the tropical and subtropical
regions of North, Central and South America.

The cottons belonging to *G. barbadense* are presumably derived
from a perennial cotton, native to Peru, called Tangnis. This variety
was introduced into the USA and by selection a new annual type
was developed, known as Sea-Island, which has the longest and
finest fibres of all the cultivated cottons. Both Tangnis and Sea-
Island cottons were brought to Egypt, where spontaneous hybrid-
ization, followed by conscious selection, gave rise to the famous
Egyptian long-staple cottons. Some of these Egyptian cottons were
subsequently reintroduced into the New World; from these, new
so-called ‘American-Egyptian’ types were bred in the USA, of
which the best known are the ‘Pimas’.

The centre of origin of *G. hirsutum* is in southern Mexico, where
an annual cotton originated, *G. hirsutum* var. *latifolium*. A few
types of this subspecies carried large bolls and were exceptionally
productive. These were introduced into the USA and subsequently
the so-called ‘upland cottons’ were developed.

How and when the first cotton with spinnable lint was used by
man as a raw material for textiles has been the subject of continuing
debate among scientists. On the basis of the evidence available to
date, the story of cotton culture begins in India. Cotton fabrics
dating back to 4,000 BC were found in excavations at Mohen-
joo-daro in the Indus River Valley (Gulati and Turner, 1928). In the
New World, cotton specimens dating from 2,500 BC were found by
Bird and Malcher (1951–2) at the Huaca Prieta site in Peru.

The annual *G. barbadense* and the annual *G. hirsutum* comprise
the bulk of the world’s commercial cotton. In Africa, *G. barbadense*
is generally cultivated in the north, usually under irrigation, while
G. hirsutum is the cotton of sub-Saharan Africa. Perennial forms of these two are still occasionally found as backyard plants for domestic supplies of lint, and the Hindi weed of Egypt is a G. hirsutum var. punctatum which has evolved an annual habit in order to survive with an annual commercial crop.

Area and Production
In 1989, the total world production of cotton seed was 49 million tonnes grown on 32 million hectares. The proportion of lint to seed is one-third. The leading countries for cotton production are China, the USSR, the USA, India, Pakistan, Brazil, Turkey, Egypt and Australia. In the same year the area sown and production in Africa were 3.9 million hectares, and 3.9 million tonnes, respectively. Important countries for cotton production in tropical Africa are Sudan, Côte d’Ivoire, Zimbabwe, Tanzania, Mali, Burkina Faso, Chad, Nigeria, Cameroon and Angola.

Utilization
More than half of the cotton lint produced is used to make clothing and household textiles. The remainder is used in industry to make bags, belts, twines, tyre-cords, etc. The short lint is used in carpets, batting and as filling material for pads and cushions. The fuzz (linters) on the seed is used to make felts, upholstery, mattresses, twine, carpets, surgical cotton, and in chemical industries for the production of rayon, plastics, paper, and photographic film.

Cotton seed contains 30% hulls, 60% kernels or meat, 5% fuzz and 5% waste. The chemical composition of cotton seed is 30% starch, 25% semi-drying oil and 16–20% protein. Cotton seed is processed to produce cotton-seed oil, one of the most important of the world’s non-drying oils. After it has been refined, the oil is used for cooking, in the manufacture of lard substitutes and margarines, and for making soap. Cotton-seed meat, containing up to 41% protein by weight, is now used as a protein supplement in human diets.

Cotton-seed cake, containing 21% protein, constitutes a high-protein feed for ruminants. It is somewhat toxic for poultry unless it is treated to eliminate the toxin gossypol. It may also be used as a nitrogenous fertilizer. Cotton-seed hulls are used as roughage for livestock and as livestock bedding, fertilizer and fuel. The dried plant is used as fuel.

Adaptation
In cotton-producing countries, annual precipitation varies from 150–1,500 mm. Cotton requires at least 450–500 mm water in order
to give high yields and in areas of low rainfall it is grown under irrigation.

Cotton is adapted to a wide range of soils, but does best on heavier soils. It is not unduly sensitive to soil reaction and is grown on soils with a pH ranging from 5–8 and higher. In Sudan, high yields are obtained on soils with a pH of up to 9.5.

Botanical Description
The Gossypium species belongs to the family Malvaceae. The cotton plant is usually considered an annual, although it is a short-lived perennial in the tropics. It is a herbaceous plant with a long tap root, and attains a height of 60–150 cm. It has a main stem from which many branches arise. The leaves arise on the main stem in a regular spiral arrangement. At the base of each cotton leaf petiole are two buds, the true axillary bud which continues to make vegetative growth (known as monopodium) and an extra-axillary bud which produces the fruiting branch (known as sympodium). The leaves are petiole, stipulate, and have three, five or seven lobes. The leaves and stems are usually covered with fine hairs.

Flowers are borne singly on short stalks: each is surrounded by three deeply divided bracteoles. Pollen is shed from the anthers just after the flowers open thus allowing a small degree of cross-pollination. The sequence of flowering is from the bottom of the plant to the top, and from the centre to the outside. The fruit (called a boll) is the enlarged ovary that develops into a 3–5 loculed capsule. The bolls are 1.5–5.0 cm long in many cultivars. The boll dehisces or splits open at maturity to expose the lint. Late unopened bolls are called bollies. The seeds are covered with lint hairs (long fibres) and usually also with fuzz (short fibres).

Flowering in the cotton plant begins from 8–11 weeks after sowing and continues until growth has stopped. Many of the young bolls and also late bolls drop off. As a result, only 35% of flower buds produce mature bolls. The period between flowering and the opening of the mature boll is about 6–8 weeks.

Upland cotton (G. hirsutum) fibres range from 18–31 mm or more in length and are of medium coarseness. The flowers are creamy white when they first open but they soon turn pink or red. The lint fibres adhere strongly to the seed. The bolls usually contain four or five locks.

American-Egyptian cottons (G. barbadense) have extra-long, fine fibres, ranging from 38–50 mm or more in length. The flowers are yellow with a purple spot at the base or claw of the petals. The lint is readily detached from the seed. The bolls usually contain three locks.
In Asiatic cottons (G. herbaceum and G. arboreum) the fibres are coarse and short, their length usually ranging from 12–21 mm. Asiatic and upland cottons have shorter boll periods than the American-Egyptian cottons.

Cultivation

Cropping systems
Cotton is an extremely good preceding crop for most other crops. It does not exhaust the soil as it removes only small amounts of nutrients. The crop residues add large amounts of organic matter that enrich the soil. It does not generally cause a build-up of diseases that harm other crops. It even has no markedly adverse effect on a following cotton crop.

The lack of apparent adverse effects of continuous cotton growing, and the importance of cotton as a cash-crop, encourages farmers to neglect crop rotation in relation to cotton-growing. Many research results encourage this attitude. Nevertheless, crop rotation is particularly effective in reducing the incidence of root and seedling diseases. Cotton can be fitted in well with maize, sorghum, millet and groundnuts in rotation. Mixed cropping has traditionally taken the place of crop rotation in Africa. The intercropping of cotton with sorghum or maize is a common practice throughout Africa.

Land preparation
Immediately after the last picking is completed, the stalks should be chopped up and the residues carefully covered by ploughing to a depth of 25–30 cm. Early burial of the residues ensures the maximum destruction of the larvae of the pink boll-worm (Pectinophora gossypiella).

After harvesting the crop that precedes the cotton, the residues should be chopped and completely buried by ploughing. Cotton requires a carefully prepared seed bed. Young plants are very susceptible to damage by insects and diseases, and therefore conditions should be favourable for rapid germination and emergence.

Cotton can also be sown on ridges. Where ridge cultivation is practised, care should be taken to ensure uniformity of ridge height and width where tillage is becoming mechanized.

Sowing
The entire production process hinges upon the success of sowing and the resulting stand of cotton. Maximum yields are not possible without a stand of uniform healthy plants. In the case of cotton, the germination percentage of seeds does not necessarily reflect the
performance of the seed when sown in the field. In many cases, seed may have a germination percentage of 90 or more; however, actual emergence in the field, even under normal conditions, will sometimes be 53% or less. In many cases, the seeds germinate, but fail to emerge or develop into healthy seedlings.

The most important seed quality is the ability and speed at which the seeds germinate and develop. Some seeds germinate and emerge slowly and some emerge from 4–5 days after sowing. The normal emergence period is 6–10 days from the time the first seedling emerges until the last seedling emerges. In some cases the emergence period is spread over a period of 25 days. The early emergers usually develop into strong and healthy plants, whereas the late emergers are normally weak and non-bearing.

Until recently, or even today in traditional farming, seeds were used in the same condition as they were when they were discharged from the gin. These seeds contain about 10% lint fibre on the seed coat and are called ‘fuzzy’ seeds. Due to the fibre on the seeds it is difficult to meter them accurately through the planters since they tend to cling together. The free-flowing characteristic of delinted seeds makes them desirable for precision sowing. This characteristic will become more important as more high-speed planters are developed and used.

Delinting is the process by which the small lint fibres are removed from the cotton seed coat after ginning. There are two main methods of delinting cotton seed. The first is by machine; where ginneries are equipped with a delinting machine, much of the fuzz is removed to yield the by-product linters. The second is the use of sulphuric acid. This may well supersede machine delinting, as the acid-treated seed is naked, flows readily and is also free of disease organisms (such as that causing bacterial blight) which may be carried on the seed coat. The operation of treating seed with acid is not difficult; and the only danger would seem to lie in the charring of the seed by prolonged immersion in the acid, or in failure to dry the seed quickly and thoroughly after washing with water, an operation which must be carried out to get rid of any excess acid. Seed so treated, at any rate in the usual sequence of operations, has to be washed in several changes of water, and at this stage floating seed can be readily separated from the ‘sinks’. The floating seeds are generally those of poor quality.

**Fertilization**
Cotton has no special preference for any particular nutrients. It is not a heavy feeder and does not make unusual demands on the soil’s resources. A 100 kg crop of seed-cotton removes from the soil in its
seed fraction some 26 kg N, 13 kg P₂O₅ and 9 kg K₂O per hectare. It also needs some boron.

As mentioned earlier, the boll is borne on a fruiting branch which originates at the leaf axil on the main stem or on a vegetative branch. As nitrogen promotes plant growth, the number of axillary positions is increased, and thus the amount of flowering is increased. The addition of nitrogen to nitrogen-deficient soils increases the total number of both flowers and bolls. A shortage of nitrogen caused a reduction in the rate of flowering and in the duration of most intense flowering. Likewise, a nitrogen shortage during early growth reduces plant size and the number of possible flowering sites. In areas with a short growing season, the late application of nitrogen will not compensate for the early loss of flowers and bolls. However, in long-season areas, later nitrogen application may produce new growth and subsequent bolls. In longer seasons, increased production during the late season, or from a second peak of flowering, can to a large degree compensate for losses due to nitrogen shortage early in season.

The overall effect of nitrogen appears to be an increase in total yield brought about by prolonging the fruiting period. Increases in yield due to nitrogen are therefore usually in the form of heavier late harvests. Acute lack of nitrogen tends to make cotton more determinate in its fruiting habit by reducing late top growth and consequently reducing the late boll load.

The timing of the nitrogen application should be regulated to avoid early-season deficiencies or excesses as well as deficiencies during the growing season. On soils low in nitrogen, an early application of N is necessary for plant development, fruiting and yield, and should be made at sowing. When the total nitrogen requirement is high and where leaching is a problem, usually not more than half is applied at sowing, with one or two subsequent applications.

The recommended fertilizer rate in Nigeria is as follows:

* for early-sown cotton (June) apply 50 kg N, 25 kg P₂O₅, and 20 kg K₂O/ha
* for late-sown cotton (July) apply 25 kg N and 15 kg K₂O/ha

The boron requirement is met with the recommended rate of single superphosphate.

**Water use**
In tropical Africa, cotton is mostly grown as a rain-fed crop, but the availability of water to the plant is very important. Irrigation, where available, is of course the perfect aid to early establishment and
increased yield. The exploitation of even very limited resources of water may therefore merit consideration.

Weed control
Young cotton suffers heavily where weeding has been delayed or neglected. The reputation of cotton as a cleaning crop is widespread, and justified (Fig. 66). Particularly in its young stages the crop has to be carefully nursed. Overshading is at least as damaging as competition for nutrients and moisture, and the slow growth of cotton for the first two months or so means that the crop cannot easily keep its head above the weeds. Around seven to eight weeks after sowing the cotton plant suddenly starts to grow quickly and begins to compete well against weeds.
Early weeding is therefore essential. Any method can be used to control weeds, but it should be done as early as possible. A first hand weeding should be done about a fornight after emergence. A second weeding is done during thinning, with a hand hoe. A further one or two weedings can be done with mechanized implements. Suitable herbicides can also be used to kill the weeds. A pre-emergence application of a mixture of norflurazone and diuron at 0.4 to 0.4 kg a.i./ha, followed by supplementary hoe-weeding six weeks later, was found to be very effective in the savanna zone of Nigeria.

**Harvesting**
Cotton harvesting, more commonly called picking, is usually done by hand in Africa. Picking cotton is a very labour-consuming task because it must be done at weekly intervals to prevent discoloration of the lint in the field. Cotton as it is picked from the plant is called seed cotton, composed of seed, lint and fuzz. One labourer can pick 20-50 kg of seed cotton a day. Care must be taken to avoid breaking off pieces of dried plant material during picking because these can easily become mixed with the cotton, leading to extra work during sorting.

Seed cotton is taken to ginneries in bags which usually weigh 27-32 kg when full. Overpacking should be avoided because it damages the lint.

**Processing**
The processing of cotton starts at the gin, a machine which separates the lint from the seed. The cotton seeds are dried artificially before ginning. First the refuse and immature bolls are removed in the ginning process, then the fibres are separated from the seed with a circular saw that catches and cuts the fibres from seed held on a screen or on slatted ribs above the blade. The lint is brushed from the blade and blown to a condenser and finally the lint is baled. A standard bale is about 1.1 m\(^3\) and, including tying material, weighs about 227 kg. Cotton seed removed by ginning is further processed to yield a valuable cotton-seed oil.

**Yields**
Farmers in tropical Africa usually obtain yields averaging 300 and 500 kg/ha of seed cotton for July (late) and June (early) sown cotton, respectively. With improved management, including sowing about mid-June, yields of up to 1,500 kg/ha may be obtained. World average yields are about 1,500 kg/ha.
Plant Protection

Diseases
In cotton-growing areas in Africa, disease is much less important than insect damage, but there are a few exceptions to this general rule. The important diseases of cotton are bacterial blight, fusarium wilt and leaf curl.

Bacterial blight, caused by Xanthomonas malvacearum, produces water-soaked lesions on the cotyledons, leaves and bolls and leads to the death of leaves and branches, the shedding of young bolls, and the premature opening of bolls. Losses of up to 50% of the crop may occur. It is carried by seed and plant debris. Dressing the seed and clean cultivation give partial control.

Fusarium wilt, caused by Fusarium oxysporum, is now a widespread disease. It is soil-borne and causes the death or stunting of the plant. Sowing resistant cultivars may help to control the disease.

Leaf curl, a virus disease, is transmitted by the white fly, Bemisia tabaci. All parts of the plant are distorted. As a precautionary measure, resistant cultivars should be sown and clean cultivation should be practised.

Insect pests
About 150 species of pests attack cotton in Africa. The following are the most serious:

* leaf suckers (Aphis gossypii)
* jassids (Empoasca spp.), which also suck the leaves
* American bollworms (Heliothis armigera)
* red bollworms (Diparopsis castanea)
* spiny bollworms (Earias spp.)
* pink bollworms (Pectinophora gossypiella)
* stainers (Dysdercus spp.), which suck the plant.

Field sanitation, including crop rotation, is a prime requirement for reducing insect pests. It is usually necessary to supplement preventive measures with the application of suitable pesticides.
KENAF
(Hibiscus cannabinus L.) and
ROSELLE
(H. sabdariffa L.)

Kenaf and roselle are important bast fibre crops. Kenaf is known by different names in different countries. Some common names are mesta, Bimlipatan jute, Bimli, Thai jute and Java jute. Roselle is very similar to kenaf and the cultivation practices for both crops are the same.

Origin and Distribution
Kenaf and roselle occur wild in tropical and subtropical Africa, which is probably their original home. They also appear to be wild or naturalized in India. Kenaf has been cultivated in Africa and Asia, especially in India, for centuries as a fibre crop for domestic use. Since the second World War kenaf has spread to most tropical countries, but up till now it has not become important in world trade.

Utilization
A good bast fibre is obtained from the stems of these crops. These fibres are used in a similar manner to jute (Corchorus capsularis and C. clitorious). The retted fibre strands, though somewhat coarser and less supple than jute, are more resistant to rotting. Kenaf and roselle fibres (often mixed with jute fibres) are used to make rope, cordage (rope for ship's rigging), fishing nets, coarse sacks, bags and canvas. The seed, which contains about 20% oil, is now also a good source of industrial oil. The oil is used as a lubricant and lamp fuel, and for the manufacture of soap, linoleum, paints and varnishes. The young leaves are used as pot-herbs. After the fibre has been stripped off, the dried stems are used as fuel.

Adaptation
Both kenaf and roselle are well suited to tropical and subtropical climates. They are grown between 45°N and 30°S. H. sabdariffa requires a more tropical climate than H. cannabinus and is more drought resistant. The optimum climatic conditions for their growth are temperatures of 16–28°C and 500–625 mm rainfall during their growing season of 4–5 months. Rainfall should be evenly distributed, i.e. at least 100 mm per month during the growing period. These crops can also be grown successfully with irrigation.

The vegetative phase is very important. To obtain the highest
yield of long fibres before flowers are initiated, the crops should be sown at a time which will enable them to make the best use of the long-day period for vegetative growth. The sowing time will, of course, depend on suitable temperatures and rainfall conditions.

These crops are not very demanding in their soil requirements and are grown on a wide range of soils, but they thrive best on a well-drained, rich, sandy loam with a neutral pH.

**Botanical Description**
Both kenaf and roselle belong to the family Malvaceae. Both plants are single-stemmed, erect, herbaceous annuals with a well-developed tap root, and grow up to 4 m tall. The stems are straight and slender (8–25 mm at the base) and seldom branched when closely sown for fibre production. The stems are more or less prickly and glabrous, and are red, purple or green. The leaves are borne alternately on the stem, on long petioles. The leaves may be cordate or palmately divided into 5–7 lobes. The flowers are borne singly in the axils of the upper leaves on the stem. The flowers are pale yellow, often with a crimson spot at the base of the petals. The fruit is a spherical, dark-brown capsule with an apical point. The capsule has five segments and contains 18–20 seeds. The seeds are wedge-shaped and brown or grey. The seeds of *H. cannabinus* are larger than those of *H. sabdariffa*. Kenaf and roselle are self-pollinating, although up to 4% cross-pollination is reported.

**Cultivation**

**Land preparation**
As kenaf and roselle are small-seeded crops, a fine seed bed is needed for their rapid germination and emergence. The land should be thoroughly ploughed, and all stubble from the previous crop should be removed or buried in the soil. All big clods should be broken down.

**Sowing**
The best time to sow is early in the rainy season so that the crop may get the maximum time for its vegetative growth during the long-day period. The seed can be either broadcast or sown in rows 20–40 cm apart. The plants are thinned out to a distance of 8–10 cm within the row. For seed production, wider spacing is adopted. The seed rate varies from: 15–25 kg/ha, depending on the species and method of sowing.

**Fertilization**
These crops are not usually fertilized, although a crop of 50 tonnes of green matter removes about 175 kg N, 30 kg P₂O₅ and 75 kg
K₂O/ha from the soil. The crops add a lot of organic matter to the soil by shedding a large number of leaves. However, a moderate dose of fertilizer may be applied.

Weed control
If these crops are sown in well-prepared moist seed beds and the other climatic conditions are favourable, germination is completed within 3–6 days, and early growth is very rapid. This means that the plants soon form a good canopy and give weeds little chance to grow. The selective herbicides alachlor and metolachlor at 1.0 kg/ha have been found very effective in controlling weeds in kenaf for up to 8 weeks after sowing.

Harvesting
Harvesting should be done soon after flowering starts, the best time to harvest being when a few (8–10) flowers are in bloom. At this stage, the fibre is at its best quality and easily separable. Delayed harvesting makes the fibres coarse and of poor lustre. The stems are cut at ground level with a hand sickle or machete and tied into bundles. The leafy tops are cut off and then the bundles are brought to a water source for processing.

Processing
This consists of retting, stripping, washing and drying the fibres. In most cases the fibres are stripped from the stems after retting the stems, but occasionally the bark containing the fibre is stripped off in ribbons by hand, tied into bundles and then retted. Mechanized ribboning prior to retting is becoming increasingly popular.

The bundles of stems or ribbons are submerged in a stream, pond or water tank and held under the surface of the water, but not touching the ground, for 10–30 days, depending on the temperature of the water, the age of the plant, and the number of retting microorganisms in the water. When retting is complete, the fibre is jerked off the stems by hand or a handful of retted ribbons are separated from the larger bundle. The fibre is then washed by swishing it back and forth on the surface of the water. The fibre is wrung out and hung up on poles to dry. When it is dry, it is sorted into different grades and baled for the factories.

Seed production
There are two ways for the farmer to produce his own seed. Either about 5% of the plants, in any corner of a field grown for fibre, are left for seed production, or a separate seed crop is grown. In the latter case, 8–12 kg seed per hectare is sown at a wider space than is used for the fibre crop. Sowing should be timed so as to avoid
excessive vegetative growth before the days are short enough to induce flowering.

The seed crop is harvested when several of the lower seed capsules have dried out, even though the plant may still be flowering. The plant is cut just below the lowest seed-bearing capsule, tied loosely into bundles, and stooked to dry out for about two weeks. When they are dry the bundles are threshed with sticks and the seed is winnowed. Threshing and winnowing can also be done by machine. The seeds should be very well dried before storing. It is advisable to treat the seed with insecticides before storage.

**Crop Protection**

**Diseases**
The serious diseases of kenaf and roselle are:

* anthracnose or tip burn (*Colletotrichum hibisci*)
* leaf spot (*Cercospora hibisci*)
* leaf blight (*Phylllosticta hibisci*)
* stem rot (*Diplostigma hibisci*)
* root-knot nematode (*Meloidogyne spp.*)

**Insect pests**
The important insect pests are:

* black flea beetles
* cotton strainer larvae (*Dysdercus saturellus*)
* cotton aphids (*Aphis gossypii*)
HEMP

(Cannabis sativa L.)

Hemp plants provide three products: the fibre from the stem, oil from the seeds, and a narcotic (bhang, hashish or marijuana) from the leaves and flowers.

Origin and Distribution
Hemp probably originated in central Asia and is one of the oldest cultivated plants. It is naturalized in parts of India as a weed of waste land. It is said to have reached China more than 4,500 years ago. It spread to the New World after its discovery by Columbus.

Area and Production
The area and production of hemp fibre and tow in the world in 1989 were 0.33 million hectares and 0.22 million tonnes, respectively. Hemp is cultivated throughout the tropics and subtropics but grows best in humid, temperate climates. Most hemp fibre production is now in China, India, southern Europe, the USSR, Japan and Chile.

Utilization
True hemp (C. sativa) provides the white bast fibres. Hemp fibre is valued for its length and strength; the individual fibres are up to 55 mm long and taper towards the ends. The fibre bundles are up to 4 m long, strong and durable, less flexible than flax, but unaffected by water. The fibres are very soft. Hemp fibres are chiefly used as a substitute for flax to make textiles, and are also used for making ropes, twines, canvas, tarpaulin and nets. As a material for rope, hemp has largely been superseded by sisal (Agave sisalana).

Hemp seeds contain about 22% protein and 30–35% of a drying oil which is used as a substitute for linseed oil in paints and varnishes and also in soap manufacture. The leaves and flowers are used as a narcotic.

Adaptation
Although hemp occurs throughout the humid tropics and subtropics, it grows best in the humid temperate climates with temperatures of 16–28°C during the growing season. It needs adequate rainfall for germination and establishment. For the production of the narcotic, warm weather and tropical conditions are required. Hemp grows best on well-drained, rich sandy loams.
Botanical Description

*Cannabis sativa* belongs to the small family of Cannabaceae. It is a stout, erect annual that grows to a height of 1-4 m. It is usually dioecious but occasionally monoecious, with male and female plants in roughly equal numbers. The main stem of hemp is hollow and produces a few branches near the top, but when grown closely for fibre production it is almost unbranched. The male flowers are in axillary, narrow, loose panicles. The female flowers are in erect leafy spikes. Male plants die soon after anthesis. Female plants continue to live for 20-40 days after pollination until the seeds are ripe. The fruits are smooth, shining, hard, ovoid achene. The seeds have a fleshy endosperm and a curved embryo. 100 seeds weigh about 2 g. The seeds mature on the lower part of the spikes first and on the upper part last. The flowers are wind-pollinated.

The hemp grown in India and Nepal and used as a narcotic is classified as a separate species, *Cannabis indica*.

Cultivation

The cultivation of hemp, either for fibre or for seed, is almost the same as that of kenaf and roselle. The seed rate is higher (about 50 kg/ha) and the depth of sowing is 1.5-3.0 cm.

Fertilization

Hemp, like kenaf and roselle, has modest fertilizer needs.

Weed control

Weeds are not a problem as hemp is a quick-growing plant and is not suppressed by weeds.

Harvesting

Hemp grown for fibre is harvested when the male plants are in full flower and the pollen starts to shed. Earlier harvesting yields a weaker fibre. After harvesting, the stalks are left in an even swathe on the ground for a few days and are then gathered up and bound. The bundles are stooked to dry, and are then ready to be processed.

Hemp grown for seed is harvested when the seeds in the middle branches are ripe. The harvesting and stooking of the plants should be done early in the morning when the plants are damp, to save seed that would otherwise be shattered.

Processing

Retting and stripping can be done in water, as described for kenaf and roselle. There is another method that can be used for hemp, known as dew retting. In this method, the stalks are left on the
ground and exposed to cool moist weather. The stalks are turned once or twice to provide uniform exposure. This process is complete when the bark separates easily from the woody portion of the stem. After dew retting, the fibres are separated from the stem, dried, and bound in bundles.

**Yields**
The average yield of hemp fibre is about 650 kg/ha, although yields of more than 2 tonne/ha are obtained in some countries. The fibre content is about a quarter of the stem weight. The average yield of hemp seed is about 400–500 kg/ha, although yields of more than 1,000 kg/ha can easily be obtained.
SISAL
(Agave sisalana Perrine)

Sisal is a crop from which leaf fibres are extracted without retting. Sisal leaves provide the most important of the world’s hard fibres, i.e. fibres so coarse that they can only be made into twine and rope. The crop and species gets its name from the small Mexican port of Sisal, from which the fibre was first exported.

Origin and Distribution
Sisal originated in Central America and Mexico where it occurs as a wild plant, as well as in cultivation. In 1893, sisal was introduced into Tanzania and Brazil, which soon became important exporting countries. Sisal was introduced into Kenya in 1903. Since then it has been widely introduced throughout the tropics and is used locally in many countries.

Area and Production
The area and production of sisal in the world in 1989 were 0.48 million hectares and 0.43 million tonnes, respectively. In Africa, the area and production in 1989 were 0.11 million hectares and 0.11 million tonnes, respectively. Brazil alone accounts for more than half of the world production of sisal. Mexico is also an important producer of sisal. In Africa, Tanzania, Kenya and Madagascar are important countries for sisal production.

Utilization
Sisal is the world’s foremost cordage fibre, and accounts for 65–70% of total cordage fibre production. The fibres are used mainly in the manufacture of twines and cordage (ropes for ships). In Europe and the Americas the fibre was used mostly as binder twine to tie harvested cereals into sheaves before they were stacked. When combine harvesters replaced binders, it was used as baler twine to tie bales of straw. It is also used as padding in motor cars and upholstered furniture, for coarse-produce bags and in the manufacture of fibre board. Sisal yarn is woven into open-mesh material for carpet backing, bags, industrial fabrics and matting.

Sisal leaves contain hecogenin, used in the partial synthesis of the drug cortisone. Sisal poles are used for building in Africa, and their pith is used for filling mattresses.

Adaptation
Sisal requires warm weather and full sunlight. It is grown in areas with an annual rainfall of 625–1,250 mm, but grows best in areas
with rainfall near the optimum 1,250 mm, well distributed throughout the year. Excessive rainfall is harmful and the plant cannot tolerate waterlogging. Sisal is grown commercially from sea level up to 1,800 m. Most of Tanzania’s estates are below 900 m, whereas in Kenya most of them are above 900 m. Sisal is grown from the hot and humid coastal belt to the cooler and drier regions of the highlands. Sisal seldom sets seeds at the lower altitudes, but in the higher altitudes in Kenya, capsules are sometimes produced.

Sisal can be planted on a wide range of soils, provided they are well-drained and fertile. Heavy clay soils are not suitable, but it can be grown on clayey soils provided that deep drains are made to drain out the excess water from the field. The soil should not be deficient in calcium.

**Botanical Description**

*Agave sisalana* belongs to the family Agavaceae. It is a perennial with a short thick stem or bole and a close rosette of leaves. A long stout flower- ing shoot or pole is produced after 5–12 years. The plant dies after the production of flowers and bulbils. The root system is adventitious, each bearer root arising from a leaf scar at the base of the bole. The bearer roots, 2–4 mm in diameter, extend horizontally in the soil at a depth of 30–40 cm. A new set of roots, known as feeder roots, arise from the bearer roots. The feeder roots are 1–2 mm in diameter and have copious root hairs. The stem or bole is a hard, thick, woody structure, with a diameter of about 20 cm and reaching to a height of 1.2 m at maturity. It has a close rosette of about 100 leaves.

Suckers grow from rhizomes, which are produced from the buds in the axils of leaves below ground level. When the rhizome emerges from ground level, it forms a sucker. Sucker production begins about a year after planting and is most prolific in the first half of the plant’s life-cycle. One plant can produce as many as 20 suckers during its life span.

A sisal plant may produce 200–250 leaves before flowering. Mature leaves are sessile, rigid and fleshy. The leaf is usually 1–1.5 m long, and its width in the middle varies from 10–15 cm. There is a highly cutinized and extremely sharp spine at the end of each leaf. Each mature leaf contains about 1,000–1,200 creamy white fibre bundles which run the whole length of the blade.

At the end of the life of the plant, a long flowering shoot, also known as a pole, emerges from the centre of the plant. After poling, the plants are generally destroyed because no new leaves are formed. Poles grow very rapidly and may reach a height of 5–6 m. Many horizontal branches, with flowers at the end of each, are produced at the top of the pole.
Bulbils are borne on the inflorescence. One pole may produce as many as 3,000 bulbils. In a real sense, the bulbils are miniature sisal plants. They measure 6–13 cm and fall to the ground when mature. With their rudimentary roots, they made excellent planting material.

**Cultivation**
Cultivation is completed in two stages: propagation in nurseries for about 12–16 months, and then raising the main crop in the field for 7–12 years.

**Propagation**
Sisal can be propagated vegetatively by suckers or bulbils, but today propagation is done only by bulbils. As already described, bulbils are formed on the poles. The bulbils are collected either from the ground after they have fallen, by shaking the poles, or by cutting the poles and shaking the bulbils into sacks. Generally only bulbils longer than 10 cm are collected. They are planted in well-prepared nurseries. The nurseries are made on loose, friable and free-draining soils. The nurseries should be fertilized with sisal waste, and should be ready for use before the rains set in. The bulbils are planted at 50 × 25 cm at a depth of 1.3 cm at the beginning of or just before the rainy season. The bulbils are left in the nursery for about 12–18 months. During this period, the nurseries should be kept free of weeds. When the bulbils are 25–40 cm high, and have 15 unfurled leaves, they are lifted from the nursery for transplanting. The fibrous roots around the base of the bulbils are usually cut off and the lowest sand-leaves are also removed.

**Transplanting**
Whether is to be transplanted on new land, or on land previously under sisal, heavy machinery will have to be used. On old sisal fields the removal of the boles is a problem and must be done by machine, as removal by hand would require far too many labourers. On new land, all the trees and vegetation must be cut down. In both cases, all the vegetation must be burnt, and then the new field can be laid out.

Before transplanting, all the transplants are graded according to size in order to obtain a uniform stand of plants. Transplanting is usually done at the beginning of the rains.

The number of plants per hectare varies from 4,000–6,000. Most sisal estates in East Africa use a plant density of 5,000 plants per hectare. This density can be obtained by planting at a spacing of 2.5 × 0.8 m, or by planting in double rows 4 m apart, with 1 m between the double rows. In this case the planting distance within the row is also 0.8 m. The planting depth is 5–7.5 cm. As far as yields of sisal
are concerned, there is no difference between single and double row planting, but double row planting permits the cultivation of a cover crop in between the sets of rows, and makes mechanized cultural practices and harvesting easy.

**Intercropping**
During the first three years, crops like maize, beans, cotton, sesame and pineapples can be intercropped in the wide space between the double rows of sisal. Intercropping is a useful source of income during the unproductive period of sisal and the intercrops also suppress weeds.

**Fertilization**
Generally no commercial fertilizer is applied. Only sisal waste is applied in large quantities. Mulching or manuring with sisal waste is very beneficial, particularly when combined with liming. Sisal responds to nitrogen and potassic fertilizers, but seldom to phosphate. If the nitrogen content of the soil is low, a dose of 50–100 kg/ha may be applied near the sisal plants. Where banding disease is prevalent, the application of potash is very beneficial. To prevent this disease, a heavy dose of muriate of potash (200–500 kg/ha) should be applied in five dressings and placed along the lines of sisal.

**Weed control**
It is important to weed the field during the first 2–3 years. This can be done by hand hoeing, mechanically, or with herbicides. Weeds may be allowed to grow during the rainy season, but are cut down at the beginning of the dry season to conserve moisture and provide mulch. Incorporation into the soil of diuron (with or without MCPA), bromacil and one or two applications of dalapon at about 5 kg/ha has been found very effective. Atrazine has also been recommended as a band spray after planting. Fluometuron is safer than diuron, but higher rates (7.5 kg/ha) are needed and the residual effect is less.

**Harvesting**
The harvesting of the leaves is done by hand with small knives with straight blades. Harvesting is usually done once a year, but in some cases it is done twice a year. The first cutting is usually made 2–3 years after planting, when the height of the majority of plants is about 1.5 m. By this time the plant has produced about 100 leaves, of which 35–40 are of economic value. Only the leaves of economic value, which are mostly on the perimeter of the bole, are cut, leaving those which are still near the meristem. A plant produces 200–250
harvestable leaves during its productive life. The number of cutting cycles depends on the age at which the plant poles, which varies with environment, speed of growth and leaf production, and cultural conditions. This is usually about eight years, but varies from 5–12 years.

Soon after cutting the leaves, the terminal spines are cut off and the leaves are bundled for transport to the factory. This has to be done quickly because the leaves must be decorticated within 24 hours of cutting.

Processing
A modern decorticator can treat 25,000 leaves, weighing 10–20 tonnes, per hour, for which 1,000 hectares of sisal are required to keep it in permanent use. First of all the waste leaf pulp, which constitutes about 95% of the leaf, is removed. The fibres from the decorticator are in parallel bundles. They are made into hanks and dried in the sun on wires stretched over poles. Sun-drying takes 8–12 hours in fine weather. On some estates, fibres are artificially dried in special machines. Drying should be done as quickly as possible in order to preserve the natural white colour of the fibres. The dried fibre should not contain more than 15% moisture.

On drying, the fibres become stiff and congealed. They are beaten lightly by metal beaters, a process known as ‘brushing’ to free the individual bundles and to remove dirt and other extraneous matter. This also combs out the shorter fibres, 7.5–12.5 cm in length, which constitute the tow and comprise 5–6% of the total output. The long or fine fibres are then sorted, graded and packed. The packed fibres contain 10–12% moisture. The fibre is baled in a hydraulic press to produce unwrapped bales usually weighing 254 kg and with a volume of 1.7 m³ per tonne.

Yields
Yields are usually expressed in kg of fibres per harvesting cycle. The average yields of productive sisal are about 900 kg dried fibres/ha per cycle, or per annum. On the best plantations in East Africa, yields of 2,000–2,500 kg of dried fibre/ha per annum are obtained.

Crop Protection
Diseases
Bole rot caused by the parasitic fungus Aspergillus niger is the most serious disease of sisal. It causes a wet bole rot and may result in the collapse and death of the plant.
**Banding disease** is caused by potassium deficiency. It causes horizontal bands, 10–15 cm wide, of purplish brown necrotic tissue across the leaves. It can cause substantial losses unless potassium fertilizer is applied.

**Purple leaf tip** is associated with exhausted acid soils and a shortage of calcium.

**Insect pests**

**Mexican sisal weevils (Schyphophorus interstitialis)** are the only major insect pest of sisal in Africa. The adult weevil is 9.5–15 mm long and dull black. It feeds on the youngest leaves, before and just after unfurling. Planting before or early in the rainy season and the application of insecticides in the soil around the young plant give some control.

**Other pests**

Elephants, baboons, monkeys, wild pigs, mole rats and other vermin can cause serious damage, particularly to young sisal.
15
SUGAR CROPS

There are two major sources of sugar in the world, cane sugar and beet sugar. Cane sugar is obtained from sugarcane (*Saccharus officinarum*) of the Gramineae family, and beet sugar is obtained from sugar beet (*Beta vulgaris*) of the family Chenopodiaceae. About 60% of the world sugar is obtained from sugarcane and the remaining 40% from sugar beet. Sugarcane is a large perennial tropical grass cultivated for its tall thick stems. Sugar beet is a root crop of the temperate regions. Before cane or beet sugars were available, sweetening materials in common use were honey and plant nectars of the sugar maple tree.
Origin and Distribution
Records of sugarcane, or its ancestors, exist in the earliest Indian writings, dating back to at least 1,000 BC, but its centre of origin has not been established. Both north-east India and some of the Polynesian islands have been suggested as centres. After exhaustively surveying the evidence, Brades (1956) concluded that Saccharum officinarum (the noble cane) originated in New Guinea, where since ancient times various forms of this thick, tall tropical cane have been grown as a native domestic garden crop for chewing. His conclusions represent the generally accepted view today. The cultivars of S. officinarum are called noble canes because their stems are large and contain more sucrose and less fibre than the canes of other cultivated species.

The dispersal of the cultivated forms of sugarcane from New Guinea is closely related to the migrations of ancient times. Brades (1956) distinguishes three main movements. The first of these brought about the introduction of S. officinarum to the Solomon Islands, the New Hebrides, and New Caledonia from about 8,000 BC onwards. The second dates from about 6,000 BC and took a westerly direction to Indonesia, the Philippines, and ultimately to northern India. The third is considered to have occurred from AD 600–1,000, reaching various island groups including Fiji, Tonga, Samoa, Hawaii and others.

From India, sugarcane was introduced to China some time between 1,800 and 1,700 BC. The dispersal of cane to the Middle East and Europe took place from India. Alexander, on his retreat from India in 325 BC, carried sugarcane to Europe, but even earlier than that it may have been introduced to Persia, Arabia and Egypt. In later times, sugarcane reached Spain and from there was taken to Madeira, the Canary Islands and Sao Tome, and then to West Africa. Columbus took sugarcane plants to the New World. Regional introductions to tropical countries of the New World occurred during the first half of the sixteenth century.

In ancient times sugarcane was used for chewing, and its juice for drinking. Sugar was extracted from the cane by primitive methods in early times in India, China, Japan, Persia, Syria, Egypt, Spain and various parts of the Mediterranean region. The commercial manufacture and refining of sugar was developed in Egypt in the ninth and tenth centuries. The modern sugar industry started in the sixteenth century and has continued to progress since then.
Area and Production
The total world area and production of sugarcane in 1989 were 16.7 million hectares and 1,007.2 million tonnes, respectively. Brazil, India, Cuba, China, Mexico, Pakistan, Thailand, the USA, Colombia, Australia and Indonesia are the leading countries for sugarcane production. Brazil, India and Cuba together produce more than half of the total sugarcane in the world.

The total area and production of sugarcane in Africa in 1989 were 1.2 million hectares and 72.1 million tonnes, respectively. The important sugar-producing countries in tropical Africa are Mauritius, Kenya, Sudan, Zimbabwe, Reunion, Madagascar, Côte d'Ivoire, Ethiopia, Malawi, Zambia, Tanzania, Nigeria, Cameroon and Zaire.

Utilization
Sugar cane is grown for chewing, drinking juice, raw sugar and centrifugal sugar. Thick noble canes, which are relatively soft with a high sugar and juice content and low in fibre, are best for chewing. The juice can also be used for drinking and sweetening. By boiling the juice over an open fire until it is almost dry, a form of sugar is prepared. This is known as ‘jaggery’ in Africa, ‘gur’ in India and ‘panela’ in Latin America. It is now usually referred to as ‘non-centrifugal’ sugar. With further improvement, all insoluble materials and all impurities are separated from the juice and the resulting product is a fine-grained, pale yellow sugar. With further improvement in the manufacturing method, raw sugar is produced, which, when further refined by washing and recrystallization to remove the last traces of molasses and other impurities, produces fine white sugar. It may be used as granulated sugar, moulded to form loaf or lump sugar, or ground to produce castor or icing sugar.

All the above-mentioned products are the cheapest form of energy-giving food. Sugar has become an important item of human diet. The per capita consumption is higher in the industrialized and developed countries than in the developing countries.

The dark brown viscous liquid separated from the crystalline sugar by centrifugals in the last stage of juice processing is called molasses. Molasses contains about 35% sucrose and 15% reducing sugars. It is an important industrial raw material. Rum is produced by the fermentation of molasses by yeast, following by distillation. Gin and vodka can also be made from molasses.

Industrial ethyl alcohol, acetone and butanol are produced from molasses. Baker's and brewer's yeast are prepared from it. It is widely used as a stock feed, either directly on in compound products. It is a valuable additive in the preparation of silage. Molasses may also be used in constructing roads.
Bagasse is the fibrous residue left after the extraction of the juice from the sugar cane. It is usually the main source of fuel in sugar factories. It is used in the manufacture of paper, cardboard, fibre board, wall board and plastics, but can also be used as cattle feed. Furfural can be produced from bagasse.

The press mud or filter mud, which settles out during the clarification of the juice in the manufacture of sugar, is used as a fertilizer. After harvesting the canes, the green tops are fed to livestock.

Adaptation
Sugarcane is typically a crop of the tropics and subtropics. Most commercial sugarcane is grown between 35°N and S. It requires high temperatures, plenty of sunlight and large quantities of water. It requires a long warm season for its growth and fairly dry, sunny and cool weather during the ripening and harvesting season. The optimum temperature for sprouting is 32–35°C; below 21°C growth is slow or fails. A relatively long growing period is essential for high yields. High temperatures during the early growth stages permit rapid growth. After a period of rapid growth, there is usually a period of slow sugarcane growth with increased sugar storage.

For high yields, sugarcane requires 1,150–1,300 mm of precipitation per annum. Moisture must be available and uniformly distributed throughout the year. In warm, dry periods, irrigation becomes essential.

Sugarcane is a short-day plant, and in tropical and subtropical areas, the plant flowers in response to short days. The plants may be topped to prevent or delay flowering.

Sugarcane grows well on a wide variety of soils ranging from sandy soils to heavy soils, but heavy soils are usually preferred. The soil should be fertile, otherwise heavy fertilization will have to be done. Sugarcane has no special demands regarding soil pH but it does not normally tolerate salinity.

Botanical Description
There are six species in the genus Saccharum, two wild and four cultivated. The wild species are S. spontaneum, with a wide distribution, and S. robustum, which is confined to New Guinea and the neighbouring islands. The cultivated species are S. officinarum, which originated in the region of New Guinea and which has long been cultivated in northern India, S. sinensis and S. barberi, which probably originated in China and India, respectively. The last two are thin canes. These three cultivated species are grown for sugar production, but S. officinarum is the principal source of sugar. The
fourth cultivated species, *S. edule*, is confined to New Guinea and is of little global importance.

Sugarcane is a robust tropical perennial grass. The plants vary in height from 4.5–6.0 m or more. The stems are from 2.5–7.5 cm in diameter and are solid. The plants have a fibrous root system which is found in the top 25–30 cm of soil.

Internodes vary in length, generally from 5–25 cm, the shortest at the bottom of the cane and the longest about half-way along its

Fig. 67 Sugarcane in flower
length. A leaf is formed at each node; they are up to 2 m long, somewhat lance-shaped, and usually quite erect, although they may droop as they get older. The plant has a paniculate type inflorescence which is called an arrow (Fig. 67). Inflorescences vary in length from 30–60 cm. Spikelets occur in pairs, one sessile and the other on a short stalk. Each spikelet usually has two flowers of which one (sometimes both) is sterile. Pollen sterility is quite common. Long silky tufts of hair are formed at the base of each spikelet. Sugarcane seed is of low viability. It is used almost exclusively in breeding projects and is of little importance in field planting as sugarcane is propagated vegetatively by stem cuttings.

The duration of the crop ranges from less than 10 months to two years, but most sugarcane is grown for 14–18 months for the plant crop and 12 months for the ratoon crop. The first crop after planting is called the plant crop. After the plant crop has been harvested, the old stools regenerate rapidly, producing a ratoon crop. The first ratoon crop usually yields only two-thirds to three-quarters of the plant crop. The yield almost always decreases steadily with successive ratoons, and therefore only two to three ratoons crops may be taken. The first two ratoon crops are more profitable than the plant crop.

Cultivation

Cropping systems
Sugarcane is a crop which is grown for many years on the same land. In most tropical countries, including those in Africa, people prefer to harvest a few ratoon crops (2–4). Thus, once planted, the crop remains in the field for 4–8 years depending on the duration of the plant and ratoon crops and the number of ratoon crops harvested. This results in the compaction of the soil. After harvesting a few ratoon crops, the land is cleared to plant a new plant crop. In some places, as in East Africa, a green manure crop is grown between harvesting and replanting sugarcane. This is a good practice as it improves the physical condition and fertility of the soil.

Land preparation
Land preparation depends on how hard and compact the land is or after how many years the land is going to be ploughed. If the land has been kept under the crop for many years, tilth is inevitably lost and the land becomes very hard. To break compaction, subsoiling becomes necessary prior to ploughing in order to attain the desired depth of tillage. To cultivate the hard land, heavy machinery is used to break up the soil to a depth of 30 cm. Where sugarcane is replanted after only one or two years, land preparation is not so
difficult. The land can then be ploughed with light machinery or bullock-drawn implements. In all cases, the land has to be prepared thoroughly by repeated disking and harrowing, and by burying all the waste and weeds in the soil. Finally the land should be levelled.

**Planting**

Since the cultivars of sugarcane are highly heterozygous, they do not 'come true' from seed produced in their tassel, and sugarcane is therefore propagated vegetatively by stem cuttings of young canes. The stem cuttings are known as sets (Fig. 68). Top cuttings from the upper portion of the mature stalks root faster and with a higher percentage of success than do cuttings from the older basal portions of the stalks, the eyes (buds) of which have become hardened from long exposure. After planting the sets, it is the bud on the intermode that grows to form a new plant. To encourage quick sprouting of the bud, the canes should be topped one week before cutting them for sets.

The canes to be used for sets should be free from diseases and pests. The sets may be short (about 30 cm) with 2–3 buds or long (60–90 cm) with many buds. In tropical Africa, smaller sets are preferred. The age of the cane used for sets depends on the length of
the growing season; in areas with a short growing season, 8-month old cane can be used but where the growing season is long the cane may be 14 months old. Setts derived from ratoon crops should be 6–8 months old. The setts are usually dipped into organo-mercurial compounds such as aretan before planting to ensure even rooting as a result of protection from soil fungi. Aretan is used in water at a strength of 0.05%. The cut ends of the cane setts are dipped into the solution and planted immediately. This treatment not only checks losses through delayed growth but improves rooting and increases yields.

About 12,500–20,000 setts with 2–3 buds are required to plant one hectare at a spacing of 1.5–1.8 × 0.6 m. They may be planted at an angle of 45° or horizontally in the base of furrows spaced 1 m apart. There are two methods of placing the setts in the furrow, either ‘end-to-end’ or ‘ear-to-ear’ (Fig. 69). With adequate soil moisture or with irrigation, end-to-end planting results in adequate stands and in a substantial saving of setts. In periods of drought and where irrigation water is scarce, ear-to-ear planting is done. This second method ensures more uniform sprouting. Similarly, some

Fig. 69  Planting of cane setts in the field: (A) end-to-end method; (B) ear-to-ear method
estates in East Africa prefer to have two rows of setts in the furrow instead of only one. This is also aimed at having a uniform stand.

The setts should be covered with only 2–5 cm soil. Deeper coverage delays emergence and often results in mortality of the setts. The depth of soil used in covering setts not only influences the rooting and establishment of the stand but also the early development of the cane stools. Subsequent tillage operations may be used to throw more soil on the growing stool and place the zone of maximum concentration of roots at a deeper depth. The young shoots usually emerge 10–12 days after planting.

Planting is usually done early in the rainy season, or in the winter season. In those parts of tropical Africa that have year-round rainfall, planting can be done at any time, but where there is a dry season between two rains, planting should be done well ahead of the dry season so that the plants can withstand a period of drought.

**Fertilization**

The balanced feeding of sugarcane results in vigorous, healthy growth and profitable yields. The kind and amount of fertilizer needed vary with the fertility of the soil and the tonnage of sugarcane desired. Sugarcane is a heavy feeder and a crop of 74 tonnes of cane per hectare removes about 107 kg N, 60 kg P₂O₅, and 300 kg K₂O from the soil (Purseglove, 1972). Sugarcane responds well both to fertilizers and innate soil fertility. Golden and Ricaud (1963) have reported from Louisiana that early in the growing season nutrients were absorbed at rates faster than rates of dry matter production. It is interesting to note the marked increase in nutrient absorption during the summer (rainy season) months of June to August. During this three-month period, 75% of the P₂O₅ and 85% of the K₂O were absorbed.

Fertilizer requirements and practices vary widely between countries, depending on local climate, soil and economic conditions and whether or not the crop is irrigated. Nitrogen must be applied in optimum amounts since too little results in low cane yields, while too much results in poor quality juice. The reduction of sucrose in the juice can be overcome by the addition of adequate potassium. Samuels et al. (1952) reported from Puerto Rico that the increase in cane tonnage from the use of more nitrogen is accompanied by an increase in tonnage of sugar per hectare. When organic sources of nitrogen in the soil are inadequate, nitrogen fertilizer must be added.

The optimum application of nitrogen appears to be 50–100 kg/ha for most of the sugar-producing countries of tropical Africa, although in some advanced countries up to 220 kg/ha of nitrogen is
given. Nitrogen is most important during the early growth of the plant crop and immediately after cutting in the ratton crops. Excessive or delayed application results in retarded maturity and a reduction in juice quality with less conversion of reducing sugars to recoverable sucrose. Nitrogenous fertilizers must be top-dressed in moist condition along the lines of canes (not on the mulch). Half the dose is given shortly after the shoots have started to grow vigorously and the other half during the rapid growth period. If the soil is not moist at the time of fertilizer application, the fertilizer should be applied in furrows and the field irrigated soon afterwards.

Sugarcane is able to use any form of nitrogen, and therefore the cheaper form of nitrogen is usually recommended. There are a few exceptions that should be mentioned. In light sandy soils, nitrate nitrogen losses by leaching are higher than those from ammoniacal nitrogen. Ammonia sources of nitrogen should not be placed on the surface of alkaline soils as this can lead to considerable losses due to volatilization.

In Africa, phosphorus and potassium applications seldom give economic responses. In some sugarcane estates, however, these are applied at the rate of 60 kg/ha each. Potassium is an essential element for sugarcane, as lack of potassium causes depressed growth. P and K fertilizers are always applied in the furrows at the time of planting.

The waste materials of sugar factories are in many places used as organic fertilizer for sugarcane. Filter mud, a by-product from the factory, contains 1–2% N and 3–4% P₂O₅. It can be applied at the rate of 5–10 tonnes/ha. Molasses contains 3–7% K₂O and is used as organic fertilizer when prices are low. An application of 5–8 tonnes/ha is sufficient. Distillery lees, the still effluent from distilling molasses, is rich in potassium and can be used as fertilizer. Bagasse is used as mulch and also composted for use as an organic fertilizer.

**Water use**

As stated earlier, tropical humid areas with more than 1,250 mm rainfall per annum are best suited for sugarcane production, but the crop is often grown in areas which receive much less rainfall. For such areas, irrigation is essential as yields of cane and of sugar are highest where adequate attention has been given to the water requirements.

The frequency of irrigation depends on the stage of development of the cane. Light, frequent irrigations are preferred when the sett is rooting and the young seedlings are getting established. As the root system extends deeper into the soil, the irrigation intervals should
be extended and the amount of water applied with each irrigation increased. During the period of rapid growth it is advisable to apply water as soon as 50% of the available water has been depleted. As the cane approaches maturity, longer irrigation intervals are scheduled to reduce the rate of vegetative growth, dehydrate the cane, and force the conversion of reducing sugars to recoverable sucrose. The furrow method of irrigation is the most commonly used irrigation system for sugarcane. This system is adaptable to a wide variation in slopes.

**Weed control**

Weed control, particularly in the early stages, is essential for the satisfactory growth of the crop. If the stand of cane is thin or lacks vigour, weeds will flourish. Sugarcane is normally a fairly slow starter, and for this reason needs all the advantages it can be given to compete against the more vigorous weeds. Once the cane plant has developed a top of several leaves it becomes a healthy competitor. Cultural practices should be such that the cane plants occupy the soil before the weeds. Adequate seed bed preparation, correct depth of planting, cultivation and herbicide treatment, are all factors which enable cane plants to avoid competition with weeds.

Weeds can be controlled by hand-weeding with a machete or hoe, by intercultivation by animal- or power-drawn machines, by flame or by the use of herbicides. Selective herbicides are now widely used for the control of weeds in sugarcane. All annuals and most biennials are controlled by destroying top growth and preventing seedling. This can be accomplished by tillage or by the use of pre-emergence or contact herbicides. Perennials present a more serious problem. A combination of tillage and herbicide application provides the cheapest effective control. Pre-emergence herbicides such as dalapon or TCA can be used to destroy the most persistent grasses. These should be applied before and at the time of planting, followed by spraying at 6–8 week intervals until the rows close in and shading renders further control unnecessary.

**Harvesting**

Sugarcane harvesting consists of stripping the leaves from the plants, topping the plants, cutting the stalks, and finally transporting the cut stalks to the processing plant. Sugarcane should be harvested when it reaches the stage of maturity with the highest sucrose content. However, the time and rate of harvesting are governed by the daily sustained crushing capacity of the factory.

In most countries the cane is cut by hand using cutlasses, but harvesting is becoming increasingly mechanized. The canes are cut at or just below ground level, as cutting higher will lead to a loss in
the crop. The leafy tops are cut off as they contain little sucrose. They should be cut at the highest fully-formed internode. Then all the dried leaves are stripped off. The cut canes soon begin to deteriorate (generally after 48 hours) and should therefore be processed immediately.

In some countries the sugarcane is burned before harvesting to get rid of waste. Burning the crop before harvesting is an operation unique to sugarcane production. This procedure does not damage the roatton crop and burning makes harvesting easier. This is generally done at night when there is little or no wind. The cane is usually burnt the night before cutting and must be harvested as soon as possible, as a decline in quality sets in about 24 hours after burning. The cane should be transported to the factory as soon as it is harvested.

**Post-harvest operations**

If a roatton crop is to be taken, the cane lines must be cleared of mulch and waste. The material should be collected into the space between the rows. When the cane is burned before harvesting there is no waste, and mechanical cultivation in each inter-row is usually practised. After burning or removing the waste from the cane lines, the stools are trimmed down to ground level. If the stools are not trimmed down, buds may develop above the ground at the base of the old canes. Such development is undesirable because the new shoots would have to rely solely on the old root system. For healthy roatton growth it is essential that buds develop below ground level and grow their own roots. Clearing the waste from the cane lines allows the soil to warm up around the stubble and this encourages sprouting of the roatton crop.

**Yields**

Where sugarcane is grown under irrigation in Africa, a yield of 100–150 tonnes of cane/ha is obtained from the plant crop and 60–90 tonnes from the first roatton crop. Under rain-fed conditions, about half of the above yield is obtained.

Production figures in terms of sugar per hectare are more meaningful than those for cane per hectare. The sucrose content of cane ranges from 9–11% in poor-quality cultivars to 13–15% in good-quality cultivars. The overall recovery of raw sugar from cane varies from 11–13%.

**Crop Protection**

**Diseases**

The major diseases of sugarcane are leaf scald, smut, red rot, mosaic disease and roatton stunting disease.
Leaf scald, caused by Xanthomonas albilineans: the earliest symptom is the presence of elongated, narrow, white to yellowish-white stripes on the leaf blades. The affected stalks produce a large number of side shoots. The most effective control of leaf scald is the use of resistant cultivars. Roguing diseased plants helps to keep the incidence of the disease to a minimum.

Smut, caused by Ustilago scitamineae: cane plants affected with smut show the characteristic whip-like structures from the centre of the leaf-roll. The most effective control measure is the use of resistant cultivars. Roguing must be done carefully to avoid scattering the spores.

Red rot, caused by Colletotrichum falcatum: affected plants may show a sudden wilting of the leaves, a loss of normal green colour, a premature drying of the older leaves and in extreme causes death of the top. When the affected stalks are cut open, reddish discolorations can be found in one or more internodes. The use of resistant cultivars is the best control measure.

Mosaic disease, earlier known as 'yellow stripe', produces a yellow-green mottling of the leaves, with stunting in severe cases. Its vectors include Aphis maidis. Fortunately many resistant cultivars are now available.

Ratoon stunting disease: infected canes show depressed growth, particularly in ratoon crops. The disease is also characterized by thin canes, orange-red vascular bundles at the nodes, and pink discoloration of the growing point. Hot water treatment of sets at 50°C for 2 hours gives effective control.

There are many other diseases of sugarcane, but they are not very serious.

Insect pests
The most important insect pests of sugarcane are sugarcane borers, white scab, and termites.

Sugarcane borers (Diatraea spp.) are the most destructive insect pest of sugarcane. Primary infection is caused by the newly hatched larvae congregating in the top 3–5 nodes of a cane. The larvae burrow into the stem, and emerge when they are adults. Sucrose is lost, the stems are weakened and young tillers may be lost. The tunnels also provide access for disease organisms such as red rot. A mixture of endrin and DDT is the most promising treatment.

White scab (Aulacopsis tegalensis) forms a mat of scales beneath the leaf sheaths. It causes severe wilting during drought. No economic control measures are currently available.

Termites or white ants (Odontotermes oedalus and O. assimilis) start damaging the sets in the soil and later in the season they attack
the crop. The leafy tops are cut off as they contain little sucrose. They should be cut at the highest fully-formed internode. Then all the dried leaves are stripped off. The cut canes soon begin to deteriorate (generally after 48 hours) and should therefore be processed immediately.

In some countries the sugarcane is burned before harvesting to get rid of waste. Burning the crop before harvesting is an operation unique to sugarcane production. This procedure does not damage the ratoon crop and burning makes harvesting easier. This is generally done at night when there is little or no wind. The cane is usually burnt the night before cutting and must be harvested as soon as possible, as a decline in quality sets in about 24 hours after burning. The cane should be transported to the factory as soon as it is harvested.

Post-harvest operations
If a ratoon crop is to be taken, the cane lines must be cleared of mulch and waste. The material should be collected into the space between the rows. When the cane is burned before harvesting there is no waste, and mechanical cultivation in each inter-row is usually practised. After burning or removing the waste from the cane lines, the stools are trimmed down to ground level. If the stools are not trimmed down, buds may develop above the ground at the base of the old canes. Such development is undesirable because the new shoots would have to rely solely on the old root system. For healthy ratoon growth it is essential that buds develop below ground level and grow their own roots. Clearing the waste from the cane lines allows the soil to warm up around the stubble and this encourages sprouting of the ratoon crop.

Yields
Where sugarcane is grown under irrigation in Africa, a yield of 100–150 tonnes of cane/ha is obtained from the plant crop and 60–90 tonnes from the first ratoon crop. Under rain-fed conditions, about half of the above yield is obtained.

Production figures in terms of sugar per hectare are more meaningful than those for cane per hectare. The sucrose content of cane ranges from 9–11% in poor-quality cultivars to 13–15% in good-quality cultivars. The overall recovery of raw sugar from cane varies from 11–13%.

Crop Protection

Diseases
The major diseases of sugarcane are leaf scald, smut, red rot, mosaic disease and ratoon stunting disease.
the cane shoots. As many as 60% of the buds of the setts are killed by termites, resulting in gaps in the stand. Insecticides such as BHC (lindane), aldrin and dieldrin have proved effective in the control of termites. Dipping the setts in a 0.25–0.50% suspension or emulsion of these chemicals is effective in protecting the buds.

Other pests
Rats cause considerable damage to sugarcane, and are very difficult to control. Elephants, hippopotami and wild pigs also cause damage to sugarcane in Africa.
16

DRUG CROPS

Tobacco and Indian hemp (Cannabis sativa) are crops used as stimulants. Indian hemp has been described in Chapter 14.
TOBACCO
(Nicotiana tabacum L.)

Tobacco is an important cash crop throughout the world. The stimulating and slightly narcotic effects of smoking, sniffing or chewing the dried, cured and fermented leaves of tobacco have led to the almost universal use of tobacco. It is now heavily taxed by many governments and provides a major source of revenue. Recently it has been shown that there is an association between cigarette smoking and ill-health, especially heart disease and lung cancer.

Origin and Distribution
Tobacco is native to tropical America, where it was used for chewing, smoking or as snuff long before it was discovered by Europeans. *Nicotiana tabacum*, which is a tetraploid, may have originated from the natural hybridization of the ancestors of the diploid species *N. sylvestris* and *N. otophora*, perhaps in northwestern Argentina where the parent species are still in contact. Tobacco was in primitive cultivation in pre-Columbian times in the West Indies, Central America, Mexico, Columbia, Venezuela and Brazil.

The Spanish carried tobacco from Mexico to Spain in 1558. From Florida it was introduced to England in 1585. The commercial production of tobacco was begun in Haiti by Spaniards in 1580 and in Trinidad in about 1595. By the end of the sixteenth century, tobacco had spread rapidly throughout Europe. The crop was introduced to Turkey in 1610, and to Virginia in 1612. It was widely spread to India and other Asian and African countries by the Spanish and Portuguese at the beginning of the seventeenth century. In Africa, tobacco was introduced successively to West Africa, East Africa, South Africa and Central Africa (Zimbabwe, Zambia and Malawi). For more than 350 years, the crop did not have much importance. It gained importance only after the First World War. Now Zimbabwe is one of the leading countries in the world for tobacco production.

Area and Production
The total area and production of cured tobacco leaves in the world during 1989 were 5.0 million hectares and 7.3 million tonnes, respectively. The important tobacco-producing countries in the world are China, the USA, India, Brazil, the USSR, Turkey and Zimbabwe.

The total area and production of cured tobacco leaves in 1989 in
Africa were 0.34 million hectares and 0.36 million tonnes, respectively. In addition to Zimbabwe, Malawi, Tanzania, Kenya, Nigeria and Zaire are important tobacco-producing countries in tropical Africa.

Utilization
Tobacco is consumed because of its stimulating and slightly narcotic effects and for its aroma. The narcotic and stimulating properties of tobacco are due chiefly to the presence of 1–3% of the alkaloid nicotine in the processed leaf. The amount varies with differences between species and cultivars, and the environments in which they are grown. The smell and flavour of tobacco are due to the liberation of various essential oils and other aromatic substances during the curing process and vary with the method used. Besides nicotine, which is the most important component of tobacco, it contains numerous other liquids, solids and gases which determine its smell and flavour, as well as being a hazard to health. Among these are resins, phenols and pyridine compounds. Flavourings such as rum, apple juice, menthol or sugars may be added to the leaf when it is processed.

Tobacco is smoked, sniffed or chewed. It is smoked in the form of cigarettes, cigars and pipe tobacco. Cigarettes are made mainly from flue-cured tobacco. Cigars are made from air-cured leaf. Pipe tobacco is usually made from blended flue- and air-cured mixtures. Snuff is prepared by grinding up air- and fire-cured leaves. The water-pipe or hookah is also used for smoking in India, Pakistan and other neighbouring Middle East countries. For this the powered form of the tobacco stem and the discarded leaves are used.

The alkaloid nicotine is extracted from tobacco waste and was formerly much used as an insecticide.

Adaptation
Tobacco is one of the most adaptable of tropical crops, and grows well in the subtropics and even in temperate climates if there is a frost-free period of 90–120 days from transplanting to harvesting. It is grown from 60°N to 40°S. The optimum mean temperatures for the growing season are 25–30°C. Tobacco requires a moderate rainfall of around 400 mm during the 3–4 month growing season, followed by dry weather when the leaves are maturing. Continuous rain during the growing season leads to disease and thin, lightweight leaves. A prolonged dry period during ripening causes secondary growth and a deficiency of gum on the leaves. Hail and strong winds cause severe injury.
Few crops as more sensitive than tobacco to even small variations in the soil. Minor variations in the soil not only determine the quality of the leaf produced but also the kind of tobacco which can be grown (cigarette, cigar, filler, wrapper or binder). Though soil requirements vary according to the class of tobacco grown, in general the crop requires a well-drained, moderately fertile, well-aerated soil with a high moisture-holding capacity. It does not tolerate waterlogging and strongly acidic and alkaline soils are also not suitable. A light soil is essential for flue-cured tobacco, and cigar wrappers. Fire-cured, dark air-cured and cigar-filler tobaccos prefer heavier silt and clay loams. Light air-cured and cigar-binder tobaccos are grown on medium soils.

**Botanical Description**

The genus *Nicotiana* belong to the family Solanaceae. The genus contains over fifty species, of which only two, *Nicotiana tabacum* and *N. rustica* are cultivated species. *N. rustica* has now been largely replaced by *N. tabacum* and is no longer important except in the USSR and India, but it was the common tobacco of the world during the sixteenth and seventeenth centuries. Its leaves have a higher nicotine content than *N. tabacum* and in recent times it has been grown mainly as a source of nicotinic acid and of nicotine for use as an insecticide.

Normally grown as an annual, tobacco is potentially a woody, shrub-like, short-lived perennial. The shallow fibrous root system often provides poor anchorage for the much more extensive above-ground development. The seedling has a single main tap root, but this is generally broken during transplanting. When young, the plant has a rosette-like growth habit, but later produces a stout, erect main axis about 1.5 m tall. The stem is unbranched, but after topping (removing of the inflorescence at a later stage), each axillary bud grows out to produce a branch or sucker. The stem bears large, simple, ovate leaves arranged spirally. The leaves vary greatly in size, thickness, texture and in the prominence of their veins, depending upon variations in cultivar. They are about 50 cm long and sessile. The number of leaves, 20–30, is usually fairly constant in each cultivar.

The inflorescence is terminal on the stalk and multi-flowered (Fig. 70). The anthers dehisce and the stigma is receptive when the flower opens so that self-pollination is the rule. Up to 4% cross-pollination does occur because bees and other insects visit the flowers for nectar. The fruit is a two-valved ovoid capsule, 1.5–2 cm long, almost completely covered with calyx. It dehisces longitudinally to
release as many as 8,000 good seeds. The seeds are minute (approximately 11,000 seeds weigh 1 g), oval to spherical, 0.5 mm long, and light to dark brown.

Cultivation

_Cropping systems_
Tobacco should not be grown on the same land for more than two years in succession and should be rotated with crops such as maize, millet, sorghum and grasses.

The cultivation of tobacco consists of raising seedlings from seed in nursery beds and transplanting the seedlings in the field.

_Raising seedlings_
Because of their minute size, germinating tobacco seeds are very delicate. This means that the seedlings have to be raised with great care. Raising seedlings in a nursery facilitates supervision of their growth and in particular allows the early detection and easier control of pests and diseases. It is also much easier to keep a seed bed free of weeds.
The area of the nursery is based on how many seedlings are to be transplanted. For example, for flue-cured tobacco 14,800–17,300 plants are planted in one hectare. To obtain this population, 25,000–35,000 seedlings will be needed, which can be raised in a nursery of 62 m². The actual bed area should be doubled to allow for pathways and a wide border.

The site should be carefully chosen to allow easy supervision. Good supervision of a poor site will give better results than a badly-managed first-class site. The site must be near a source of water to facilitate irrigation. A wide range of soil types is acceptable but top soils with a high clay content are better avoided. A fertile loamy soil in good condition is ideal.

The size of the individual beds should be of a standard unit length and a width of 1.0–1.2 m. The width is a matter of operating convenience to ensure that the centre of the bed can be easily reached from the pathways without standing on the plants. The longer the beds the less land is wasted on pathways. A series of beds should be made with a level surface and raised above the path level. A firm but not solid base is required over which a loose tilth is needed. Large clods are undesirable. A fine powdery surface is also undesirable since it is likely to seal with constant watering.

The sterilization and fumigation of nursery beds have become common practice in most tobacco areas. The aims are to control weeds by killing their seeds, and to destroy nematodes and other disease organisms. Steaming is a very effective method of sterilization, but it is very expensive, time-consuming and troublesome. Steaming is now little practised outside North America. The substance showing the most consistent efficiency over a wide locality is methyl bromide. The area to be treated must be well cultivated to a good tilth and be just moist. Too dry a soil does not retain the vapour and too much moisture prevents the penetration of the gas. It is usually applied to individual beds under a gas-tight plastic sheet which has been carefully sealed around the edges with soil-filled bags, or by burial in the soil. About 0.45 kg of gas, released through one or more outlets, over 9.3 m³ is an adequate dosage.

Nematicides are used only to control nematodes. They are placed or injected at least 25 cm deep in well-cultivated soil free of large clods. A light watering immediately after treatment helps to retain the fumigant. A special gun is used to inject the nematicide into the soil. Burning is the most effective way of controlling weeds.

A seed bed is expected to produce a substantial number of seedlings fairly rapidly. To achieve this, some fertilizer must be applied. A fertilizer mixture of 6:18:6 (N:P:K) can be used at a rate of 0.45 kg for 3.0 m² (Akehurst, 1971). Fertilizer is applied after any
sterilization process. If early growth is slow or the plants are very yellow, nitrogen in nitrate form can be applied as a top dressing. Nitrogen applications should be avoided within two weeks of the plants being pulled, as this might make them too soft to withstand the rigours of transplanting.

The seed should be of high quality, i.e. well-cleaned and of good germination capacity (normally not less than 95%). The rate of seeding depends on the plant population in the seed bed. The seedlings must always be dense enough to force some early stem elongation, but the greater the density the greater will be the tendency to grow upwards and the thinner will be the stems, resulting in weaker plants. Seedling density studies (Dean et al., 1960) showed that those spaced 5 × 5 cm in the bed had greater root development after transplanting than those spaced 2.5 × 5 cm. A seed rate of 28 g is considered adequate for 335–420 m². The seed is invariably broadcast. The small size of the seeds makes it very difficult to sow them uniformly and to facilitate uniform sowing, an inert material is mixed with the seed. Ashes, sand or any similar material (but not fertilizer) can be used and the mixture is applied by hand or with a seeding machine. After sowing, the beds are raked very lightly or a thin layer of sand is scattered over the seeds to bring them into close contact with the soil.

It is essential to keep the surface of the bed moist from the time of sowing until the seedlings have their roots well down. The first 10 days are most critical and the seed bed must be watered regularly. In addition, the beds are covered with either a plastic sheet, a cloth, or chopped grass mulch to protect the seedlings from cold, wind and moisture loss. The young seedlings grow through the mulch without any adjustment to their density. The amount of cover is decreased gradually. Besides watering and the regulation of cover, the other operations necessary during seedling growth are weeding and thinning. The weeds should be removed as soon as possible. Thinning out thick patches of tobacco seedlings is also desirable as soon as the plants are big enough to grasp. In some places it is the practice to replant such surplus seedlings immediately into areas of the bed which may be bare. In Japan seedlings are first raised in small beds and then transferred at about 27 days into larger beds where they are spaced about 7.5 cm apart to grow to transplantable size.

As the seedlings approach transplantable size they need to be prepared for the shock of transplanting in the field. Where transplanting is done during the rainy season, the cover has to be completely removed at an early stage so as to accustom the plants to light. Where moisture is largely or completely under control, the
plants are hardened off by restricting watering during the last three weeks of seed-bed life.

**Transplanting**

Height is a convenient basis for judging when a seedling is ready for transplanting. Normally the height should be about 10–15 cm from the root crown to the bud. Even in a good seed bed and with good management, not all seedlings grow uniformly. The total number of transplantable seedlings will only be obtained in 3–4 pullings over a period of 3–4 weeks. Normally half to a third of the total seedlings in a seed bed will be available at the first pulling. If possible, top dressing with fertilizer can be done after the first pulling. Pulling should be done plant by plant, selecting only those of the right size. Only careful handling will ensure that the roots retain as much soil as possible. Seedlings should be kept shaded before transplanting to avoid unnecessary water loss. It is particularly important that the roots should stay cool and moist and pulled seedlings should be transplanted quickly. Delayed transplanting of pulled seedlings results in progressive crop yield reduction.

The field into which the seedlings are to be transplanted should be ready to receive the seedlings. While a fine tilth is not necessary, it is important to have the soil fairly well broken down so that there are no large clods. In some places planting is done on ridges. In that case, ridges of normal height may be made well in advance. Transplanting should normally be done in the afternoon and there should be sufficient moisture in the soil at the time of transplanting. The seedlings are planted in rows 60–100 cm apart. The distance between the plants in a row varies from 30–60 cm, depending on size of cultivar and soil fertility. These row and plant spacings provide from 0.4–1.0 m² per plant. The plant population density ranges from 55,000 plants/ha to as low as 16,000 plants/ha. Higher densities tend to promote the growth of smaller, thinner leaves, which is desirable. If soil moisture is inadequate at the time of transplanting, a small amount of water should be applied to each plant just after transplanting. Sometimes it is advisable to cover the transplants with dried grass or leaves during the daytime for 2–3 days until they are established.

**Fertilization**

Fertilizer management is of critical importance in tobacco production as it makes or mars the quality of the leaf. A yield of 1,000 kg leaves/ha removes approximately 90 kg N, 22 kg P₂O₅, 120 kg K₂O, 78 kg calcium, 11 kg magnesium and 4.5 kg sulphur per hectare. Chapman and Carter (1979) have reported that the
potassium:calcium ratio in the leaves affects the rate of burning and
ash quality – both important quality factors. The ratio should be 1:1.
Phosphorus deficiency leads to dark green, lower quality leaves.
Excessive nitrogen increases the nicotine content of the leaves.
Nitrate forms of nitrogen are more desirable for high yield and leaf
quality than are ammonia forms. Because chlorine lowers leaf
quality, fertilizers with excess chlorine (such as KCl) should be
avoided.

Lower fertilizer rates generally increase leaf quality but may
decrease crop yield. The type and amount of fertilizer are adjusted to
the kind of tobacco being grown and the soil on which it is grown.
Fertilizer for flue-cured tobacco should be low in nitrogen but high
in phosphate and potash. Excessive nitrogen produces a strong
flavour and an undesirable dark green leaf that cures with dark
colours. For other types of tobacco, the fertilizer should contain N, P
and K in the ratios 1:2:2 or 1:2:3. The phosphate content is needed to
stimulate root development, and high potash for leaf quality and
‘burning’ properties.

Rates of N, P, O_3, and K, O for different types of tobacco vary from
40–100 kg, 50–100 kg and 100–150 kg, respectively. Fertilizers
should be banded 7.5–10 cm on one or both sides of the seedlings
and about 5 cm below the soil surface for best results. This practice
prevents fertilizer injury to the seedlings.

**Topping and suckering**

Leaf quality is enhanced by topping and suckering the plants. When
the flower buds are formed, the inflorescence and the topmost
leaves are removed. This operation is known as topping. It improves
the yield, quality and type of leaves produced. The time and height
of topping depends upon the class of tobacco grown, the type of soil
and the spacing. 8–10 good leaves are usually left on the plant for
fire-cured tobacco, 10–12 leaves for flue-cured tobacco, and 9–11
leaves for air-cured tobacco. Low topping causes an increase in the
size and thickness of the leaves.

The tobacco plant has a determinate growth form, terminating in
a flowering head, which by apical dominance, checks the growth of
axillary buds. Topping allows the axillary buds to grow. These
lateral buds are called suckers and they are removed when about
7–12 cm long. The removal of suckers is termed suckering. Sucker-
ing is done weekly as more and more suckers develop. Sucker
growth can be controlled by hand-clipping, with chemicals such as
maleic hydrazide or with some very effective oils.

Topped and suckered plants exhibit an increase in the growth of
the root system and the thickness of laterals, and show greater
response when topping is done early (just before any flower opens). Subsequent suckering has more influence on fibrous root development. A large root area increases soil anchorage and may raise the level of nicotine synthesis. Through topping, the leaf area is increased mainly because of an increase in the width of the leaf particularly near or above the middle. Leaves on a topped plant become less pointed. The thickness and dry weight of leaves are also increased by topping. Observations have shown that the ripening of the normally grown crop is retarded by topping and suckering (Akehurst, 1971).

**Weed control**
Tobacco requires very clean cultivation and weed control is the most expensive and time-consuming operation. Under no circumstances should weeds be allowed to grow in the tobacco field as they not only greatly reduce yields but also reduce the quality of the cured leaf and hence the market price. Weeds should be removed while still small by repeated cultivation, sometimes 5–7 times during a season. Mixtures of MCPA and TCA applied 15–20 days before transplanting have been found very effective in controlling weeds. Diphenamid can be recommended as a spray at or after transplanting. Broomrape (Orobanche spp.) is a serious weed pest of tobacco. Numerous herbicides have been tested but only a few have been effective. In Cuba, allylalcohol at a concentration of 0.2% in water sprayed on Orobanche and the soil around the parasitized tobacco has killed the parasite without injuring the crop. Watering immediately before or after application was found to be helpful.

**Harvesting**
There are two methods of harvesting: the leaves may be cut off individually so that all are gathered at the same stage of ripeness; or the whole stalk may be cut and the leaves not removed from it until they are fully cured. The stage of ripeness is directly related to the sugar content of the ultimate product. Flue-cured tobacco has the highest sugar content and is therefore harvested when fully ripe. All other types have a low sugar content and are harvested when much less ripe.

Ripeness is indicated by a lightening of the colour of the leaf blade, a whitening of the midrib and an angle of approximately 90° between the stem and the base of the midrib. In Central and East Africa, flue-cured, air-cured and fire-cured tobacco are harvested by cutting individual ripe leaves, whereas in the USA and most other countries, the air- and fire-cured, and most cigar tobacco (except the wrapper) are harvested whole by cutting the stem near
ground level when the largest number of the leaves are at the correct stage of ripeness. This is usually 40–55 days after topping. The leaves are cured on the stems, which are tied to poles, and the leaves are wilted before they are transferred to the curing barn.

In Africa, in flue-cured tobacco, 1–3 leaves are primed at a time; the first are taken at about the time of topping, i.e. 60–75 days after planting. From then onwards priming is done at approximately weekly intervals, there are usually 6–9 primings in all. In fire- and air-cured tobacco, more than two leaves are primed at a time and only 2–3 operations may be needed. The interval between the two primings is about two weeks. In other countries, flue-cured and cigar-wraper leaf is harvested individually as the leaves ripen, beginning with the lowest leaves. The lowest leaves ripen 80–100 days after planting and 14–21 days after topping. There also 2–4 leaves are taken at each priming, which is continued at weekly intervals. The leaves are strung back to back in alternate pairs on either side of sticks and are hung in the barn for curing.

**Curing**

Curing may be described as the process by which the harvested tobacco leaf is made ready for the market. It is essentially a drying process whereby most of the moisture in the harvested leaf is removed. The process of drying is conducted in such a way as to produce certain well-defined and desirable qualities in different types of tobacco. Depending on the method of harvest and the maturity of the leaf at the time of harvest, there are four principal methods of curing: flue-curing, air-curing, fire-curing and sun-curing. No method of curing can induce the development of qualities which are not potentially present in the tobacco leaves, but imperfect curing can destroy these potential qualities, so constant care and attention are required.

Very brief descriptions of the different curing processes are given below. Flue-curing is the shortest process (3½–6 days), air-curing the longest (3–6 weeks) and sun-curing intermediate (2–4) weeks.

Flue-curing techniques aim to keep the leaf alive until almost all the starch has been converted to sugar but before any appreciable amount of these sugars has been reduced further. The desired stage is conveniently denoted by a colour change; once it has been reached, the leaf is fixed in that stage by the use of artificial heat which dries it out and kills it.

Sun-curing is done by exposing the leaves to the sun but not under any precise control. For the first 2–3 days the leaves are air-cured and then they are put in heaps for 24–36 hours to ferment before they are exposed to the sun.
Air-curing, being a longer process, keeps the leaf alive until the initial sugar content has been completely oxidized away. It may be under fairly good control or no control at all. Curing is done under normal atmospheric conditions in a wooden or grass barn.

Fire-curing is usually done in a barn. The leaves are hung for 4–7 days to yellow and are then smoked for 12 hours by burning dried grass, husks, twigs, etc., in a pit on the floor. This produces the creosotic and distinctive aroma of fire-cured tobacco.

Yields
Very variable yields of tobacco are obtained. In Africa, yields of cured leaves vary from 400–2,000 kg/ha depending on the standard of husbandry. The highest yields in tropical Africa are obtained in Kenya and Zimbabwe, where the average yield is more than 2,000 kg/ha. The average yield in the United States and France is about 2,400 kg/ha.

Crop Protection
Diseases
The main diseases of tobacco plants in Africa are damping off, frogeye, brown spot, anthracnose, Granville wilt, mosaic and rosette.

Damping off, caused by Pythium spp. and Corticium solani, occurs in nurseries. The stems are attacked at soil level. The plants fall over and the leaves then rot into a shapeless slimy mass. Affected patches and surrounding areas may be dusted with copper fungicide.

Frogeye, caused by Cercospora nicotinae: circular spots with white or pale brown centres and narrow dark brown margins are produced on the leaves. The disease also causes spotting in the barns during the early stages of curing. Normally, a weekly spraying of Bordeaux mixture or a proprietary copper compound will provide adequate control.

Brown spot, caused by Alternaria longipes: these brown spots with concentric rings can be distinguished from frogeye by the presence of blackish patches on the stem, midrib and pedicels. Copper compounds and maneb have been used with some success. Fungicides can be useful but application must be started at the first sign of infection and then rigorously continued.

Anthracnose, caused by Colletotrichum tabacum normally occurs in nurseries. Water-soaked patches are formed on the lower leaves. Control can be effected with zineb or thiram.

Granville wilt, caused by Pseudomonas solanacearum, causes decay of the roots, followed by wilting. Copper-based sprays or dusts provide effective control both in the nursery and in the field.
Mosaic is a virus disease transmitted by mechanical contact. The common symptom is dark green and yellowing mottling, but the disease can also cause spotting and scorching. Control is through prevention and the destruction of all old tobacco debris.

Rosette is a virus disease transmitted by aphids (Myzus persicae): the symptoms are stunting and the production of many small leaves. Sometimes many axillary shoots are produced. Early planting to enable good growth before a large build-up of aphids occurs is an important control measure.

Insect pests
The insect pests that damage tobacco are cutworms, wireworms, aphids and thrips.

Cutworms (Agrotis ypsilon) cause damage in East and Central Africa. It is characteristic of cutworms that they operate on the surface of the soil and the stems are always cut just above ground level. They feed only at night.

Wireworms (several genera of the family Elateridae are involved) feed on roots and organic matter and readily attack the roots of newly transplanted tobacco. Parathion or diazinon can be used to control this pest.

Aphids (Myzus persicae) feed on tobacco. They have a remarkable reproductive ability and are virus-transmitting agents. Aphids can be controlled with malathion or parathion.

Thrips (Thrips tabaci) are tiny, slender insects. The eggs are laid on the leaf epidermis and both nymphs and adults feed on the leaf. Control measures are similar to those for aphids.

The tobacco crop is also attacked by mole crickets (Scapteriscus acletus), stem-borers (Scrobipalpa heliopa) and hornworms (Manduca sexta).
Tea, coffee and cocoa are the major non-alcoholic beverages. Because of the refreshing and stimulating effects of the alkaloid caffeine or related substances which they contain, and because of their pleasant aroma and flavour, they are very popular drinks. About half of the people in the world drink tea or coffee regularly. The aroma and flavour are derived largely from essential oils in the plant parts. Cobley and Steele (1977) have reported that in small amounts caffeine acts on the central nervous system to increase mental activity and decrease fatigue, but if taken in excess it can be harmful. Caffeine also aids digestion by stimulating the increased production of digestive juices. It has a diuretic effect, increasing the excretion of uric acid. The plant parts from which tea and coffee are made contain 1–3% caffeine, and cocoa seeds contain 1–2% theobromine, which is an alkaloid similar to caffeine.
TEA
\textit{(Camellia sinensis)}

Tea is a beverage prepared from the processed, dried leaves and buds of \textit{Camellia sinensis}.

\textbf{Origin and Distribution}
Considering the localities in South-East Asia where various types of tea are now established, it is likely that they have originated and been dispersed from a centre near the source of the river Irrawaddy (in Burma). From there they spread to south-eastern China, north-eastern India, Laos and Vietnam. From South-East Asia, tea has spread into many tropical and subtropical countries.

Tea has been used as a beverage for between 2,000 and 3,000 years in south-eastern China, but the commercial cultivation of tea is hardly 200 years old. The tea industry in its modern form started in India between 1819 and 1834, from seed originating in China, but after the discovery of wild tea in Assam and Manipur (India), commercial plantings were made with these local types from 1836 onwards. Tea cultivation was started in Java (Indonesia) in 1824 but remained unremunerative until the introduction of Assam types in 1878. In Sri Lanka, the commercial cultivation of tea began in the 1970s. Tea was first planted in the USSR in 1846, but the first successful plantations in Georgia were begun in 1895.

In Africa, tea was being grown in the Durban Botanic Garden in 1850 and developed into a local plantation industry. The oldest continuing tea industry in Africa is that of Malawi. Tea was first introduced into Malawi in 1886 and the first estate was planted in 1891. Specimen plants were being raised in the three East African countries at Limuru (Kenya), Entebbe (Uganda) and Amani (Tanzania) at the turn of the century, but commercial production was only started in the decade 1920–30.

\textbf{Area and Production}
The area and production of tea in the world during 1989 were 2.67 million hectares and 2.48 million tonnes of processed tea, respectively. During the same year, tea was grown in Africa on 0.18 million hectares with a total production of 0.3 million tonnes. For tea production, India, China, Sri Lanka, the USSR, Japan and Turkey are the most important countries. The important tea-producing countries in Africa are Kenya, Malawi, Tanzania, Zimbabwe, and Rwanda.
Adaptation
Tea cultivation is confined mainly to the subtropics and the mountainous regions of the tropics. It is grown between 40°N and 33° S. Near the equator, tea is grown at high altitudes varying from 1,200 to 2,200 m. Although tea tolerates dry spells, it only gives a continuous flush of growth when there is adequate soil moisture throughout the year. In long dry spells tea must be irrigated or flush growth ceases, the bushes wilt and eventually defoliate. Most tea in East Africa is grown in areas that receive a well-distributed annual rainfall of 1,500 mm or more. In general, mean minimum temperatures below 13°C are likely to bring about damage to the foliage and a cessation of growth; mean maximum temperatures above 30°C are likely to be accompanied by humidity so low that a similar cessation of active development is inevitable. It may reasonably be said that tea is suitable as a crop in regions with moderate to high rainfalls in excess of evaporation, and which maintain equable temperatures with high humidity throughout the greater part of the season. Hail and strong winds can cause much damage.

Tea is grown on a wide range of soil types. Some of the best tea in the world is grown on the alluvium of the Brahmaputra valley in India. On the other hand, many good tea soils are old sedentary soils derived from archaic rocks such as gneiss in Darjeeling, Sri Lanka and Tanzania, or granites in Uganda and certain areas in Japan. Volcanic rocks are the basis of tea soils in Indonesia, Kenya and parts of Tanzania (Eden, 1977). Whatever the type, the soil should be deep, permeable, well-drained and acidic (pH 4.5–6.0).

Botanical Description
Camellia sinensis belongs to the family Theaceae. Tea is a shrub or straggling tree which grows wild to a height of 10 m or more, but in cultivation the growth habit of the plant is carefully controlled by pruning. The young shoots are continuously harvested to be processed. The plant has a strong tap root with lateral roots which give rise to a surface mat of feeding roots which lack root hairs when mature. The roots store starch as food reserve which becomes available for regrowth after periodic, severe pruning. Normally, crops should be pruned at the end of or soon after periods of natural dormancy, when starch reserves in the roots are most plentiful.

Now leaves and branches develop from buds in the axils of mature leaves. These leaves are evergreen, obovate-lanceolate in shape. Normal mature leaves are serrated at the margin. Leaves are generally glabrous with some sparsely distributed hairs on the undersurface. The buds and internodes are more profusely hairy.

The globular flower buds are borne in the axils of scale leaves,
and develop either singly or in clusters. The flowers have a short pedicel and a persistent calyx with 5–7 sepals and the same number of petals. The stamens are long with yellow twin-celled anthers. The ovary is hairy and has a single style split into 3–5 arms. The flowers are white and smell sweet. Each flower produces a capsule which usually contains three seeds. The seeds are brown, about 1.3 cm in diameter and spherical. They have tough seed coats.

**Cultivars**
Despite great variation in the crop, only two main groups of cultivars are recognized and these have the status of botanical varieties. They are:

* *Camellia sinensis* var. *sinensis* (China tea), a slow-growing dwarf tree, with small, erect, comparatively narrow, markedly serrate, dark green leaves. The flowers are borne singly. The tree is resistant to cold and adverse conditions, but low-yielding.
* *Camellia sinensis* var. *assamica* (Assam tea), a quick-growing, taller tree with large drooping leaves. The flowers are borne in clusters of 2–4. It is well adapted to tropical conditions.

**Cultivation**
The cultivation of tea is covered in two phases, raising cuttings in the nursery and transplanting them in the field.

**Raising cuttings**
The success of vegetative propagation depends on the selection of mother plants that are above average performance as regards vigour of growth and manufacturable quality of leaf, and on the technique of propagation used.

Mother trees are allowed to grow for about six months after pruning, to provide long stems for cuttings. Single-leaf internode cuttings are taken immediately above a leaf and axillary bud. The top two or three internodes are discarded. Only the green or slightly reddening stem portion is utilized for cuttings. A sharp knife should be used for cutting, and the cut should be sloping. Cuttings must be kept shaded and wet, preferably floating in water, until they are planted.

It is advantageous to plant cuttings in polythene sleeves instead of directly in a nursery. The cuttings will grow best if the sleeves are two-thirds filled with fertile top soil and the top third with rooting medium (e.g. friable acid subsoil). One cutting is planted in each sleeve. The stem should be pushed into the sleeve only to such a depth that the petiole and tip of the leaf do not touch the soil. The sleeves should be kept in the shade. The cuttings must be watered at
regular intervals. When the roots are about 10 cm long and shoots have developed, the shade is removed to allow the cuttings to harden. Cuttings are ready for transplanting in the field when their roots reach the bottom of the sleeve and when their tops are 20 cm high. This stage is reached in about 6–10 months.

Instead of planting the cuttings in sleeves, they may also be planted in shaded nursery beds. Careful, controlled watering is essential.

Transplanting in the field
Although cleared virgin forest is usually the most suitable land for tea, it can be cultivated on any cultivable land. All the vegetation on the land, including the tree stumps, should be removed and burnt off the field as tea does not grow on patches of wood ash. Before planting, correct soil conservation and weed control measures should be taken.

The usual size of the planting holes for sleeved plants is 40 cm deep and 22.5 cm square. The most common spacings between the holes are 1.5 × 0.75 m or 1.5 m square. With these spacings, there will be 5,000–7,000 plants per hectare.

The bottom of the sleeve is removed and the sleeved plant is held in the middle of the planting hole. The top of the sleeve must be level with the surface of the soil in the field. The polythene is then carefully cut and removed so that very little soil is disturbed. The hole is gradually filled with top soil which is packed down firmly. To encourage early growth, 20–30 g of common superphosphate can be added to the soil used for refilling each hole.

Shaping or frame formation
During the first few years of the tea plant’s life in the field, shaping is done to turn what is naturally a small tree into a low, wide and spreading bush. The aim of this operation is to maintain a convenient height for plucking, to induce vigorous vegetative growth and to ensure a continuous supply of flushes. Shaping of the tree in this manner is also called framing. The frame must be wide enough to allow a continuous plucking table with no gaps between the bushes. The China types, being dwarf and slow-growing, require relatively little pruning, whereas Assam teas and Assam China hybrids have to be kept within bounds with heavy pruning.

In frame formation the main shoot of the young shrub is cut back to encourage the development of lateral shoots. When sleeved cuttings are used, each usually produces one dominant stem. When this attains a height of 30–35 cm, it should be cut down to 15 cm above ground level to encourage the growth of lateral shoots. The laterals
are also cut down to a height of 15 cm. The pruning should be continued until all the shoots attain a suitable thickness at a height of 40 cm above ground level. Usually these pruning operations are done at yearly intervals. These severely pruned bushes come into bearing 2.5–3 years after planting.

Tipping in
As soon as the frame is formed after repeated pruning, the new shoots are allowed to grow for about 3 months, after which they are checked by the procedure known as tipping in. This involves the removal of three leaves and a bud from each shoot when this amount of growth has appeared above the desired height of the plucking table (60 cm). Generally 2–3 tippings in are done at 2–3 week intervals.

Fertilization
In tea, one is interested in leaf production and nitrogen is therefore the most important element. Everywhere, there has been a positive response to nitrogen. The response is greater in the presence of phosphate and potassium in the soil. To obtain a cumulative response, nitrogen must be applied every year. In the first two years nitrogen should be applied at half the rate for mature tea plants. The rate for mature tea plants varies from 100 to 200 kg/ha. To obtain a better response to nitrogen, phosphorus and potassium must also be applied. The ratio of the three elements should be 25:5:5. Calcium ammonium nitrate should not be used, as it contains enough calcium to restrict the potassium uptake of the crop. Fertilizer can be applied at any time of the year and the full dose of fertilizer may be applied at one time.

Weed control
In the first 2–3 years, when the tea bush is young, weeds grow prolifically between the bushes. When the bushes mature, weeds are suppressed by the shade, by the roots of the tea bushes, and by the mulch of prunings. In the early years, therefore, effective weed control measures should be adopted. The methods of controlling weeds are hand pulling or hand cultivation. If a herbicide is used, care should be taken to select one which does not have an adverse effect on the tea bush.

When preparing the nursery bed, perennial grasses should be controlled with dalapon or amitrole 6–8 weeks before planting the cuttings. In the nursery, simazine can be used to keep the ground free of weeds. Where weed growth is present at the time of spraying, a low rate of paraquat may be mixed with the simazine. In established tea, paraquat can be applied 3–4 times per year.
Harvesting or plucking

Harvesting consists of plucking the tips of the newly grown vegetative shoots above the plucking table. These tips should have the terminal bud and 2–3 leaves immediately below it, together with the intervening stalk. The best tea is made from a flush with a bud and two leaves (fine plucking). Coarse plucking (a bud and 4 leaves) yields a lower quality tea.

Plucking is usually done by women using the thumb and forefinger. The plucked shoot is transferred to a basket on the plucker’s back. The leaf must not be compressed in the basket or in the hand. After plucking, the leaves must be kept in the shade.

The length of time between flushes and for the plucked shoots to produce a new shoot ready for plucking varies with the plucking system used (i.e. fine or coarse plucking) and environmental conditions. Plucking is usually done every 7–10 days at the lower elevations and every 14 days in colder climates.

A skilled plucker can pluck 0.08 ha, or 15–35 kg of green shoots per day. The economic life of a tea tree is 40–50 years, though in India and Sri Lanka it is 70–100 years.

Processing

The final product, black tea, is made in the factory from the green leaves after passing through the various stages of processing. The whole process is completed in about 2 days.

Withering is the first stage in the processing of tea. This is carried out by spreading the picked leaves thinly on ‘tats’ made of tightly stretched jute, hessian or wire netting in a room where warm air is blown over the leaves. The average time for withering is 18–20 hours when ‘tats’ are used. During withering, the leaves lose about 40–42% water and become flaccid and permeable to the juices which the subsequent rolling operation will wring out and spread evenly over the surface of the leaves.

Rolling: the withered leaves are then passed on for rolling, which twists the leaves, breaks them up, expresses the juices and spreads them in a thin film on the leaf surface. The net result is that the catechins and enzymes, originally separated in the leaf, are thoroughly mixed and exposed to the atmosphere. The green colour diminishes and the brown or coppery colour of the oxidation products begins to appear. The final product is compressed into lumps.

Breaking and sifting: the leaf lumps are then passed through a machine, the ‘roll-breaker and sifter’. This machine performs three functions: it cools the leaf, it aerates the mass, and it sieves out the particles of small size, so separating the leaf into portions that will
be reasonably uniform in their rate of fermentation, a process which has already begun during rolling.

**Fermentation:** The sifted particles are spread out in thin layers in order to continue the fermentation process. During fermentation the leaf changes colour and becomes a dark copper colour, and the typical tea aroma develops. The time of fermentation should be as short as possible, not more than two hours. After this there is appreciable loss in quality.

**Firing:** The fermented tea is treated with a forced draught of hot air at a temperature of 82–93°C, and is dried to a moisture content of 3%. This process is known as firing.

**Grading and sorting:** The dried tea is graded and sorted in a room with a relative humidity of 60–65%. If the humidity is not controlled, the moisture content of the leaf may increase to 5–6%. Grading is based on colour and fineness of the particle. Before tea is packed, the accumulated series of daily batches of each grade are bulked and mixed in order to ensure as high a degree of uniformity as possible. The tea is then packed into plywood chests lined with aluminium foil and paper.

**Yields**

5 kg of green leaf shoot produces about 1 kg of made tea. The average annual yield of made tea in East African countries ranges from about 500 kg/ha in Uganda to more than 2,000 kg/ha in Kenya. Yields of up to 3,000 kg/ha could be achieved in these countries.

**Crop Protection**

**Diseases**

The monocultural conditions under which tea is grown commercially make the transmission of diseases more difficult to control. This problem is further aggravated by the fact that in many tea-growing areas virtually no other form of cultivation is practised. An epidemic outbreak of a disease can affect very large areas in a comparatively short time. In Africa, tea is seldom attacked by the diseases that damage the crop in other parts of the world. Only two diseases deserve special attention in Africa.

**Armillaria root rot** is caused by *Armillaria mellea*, a saprophyte living on dead stumps and roots of forest trees or tea bushes. If the root surface of the tea bush is damaged by cultivation or by boring insects, *Armillaria* can enter the roots and become parasitic. Once in this stage, the main root system rots away and the bush eventually dies. The leaves turn yellow and fall off and sheets of white mycelium can be found between the bark and the wood. Control is
the thorough uprooting and burning in situ of the affected bush and any other source of infection.

**Tea yellow disease** is caused by a sulphur deficiency. The earliest symptom to develop is mottling of the leaves. The network of veins remain green while the rest of the leaf gradually loses its chlorophyll and turns yellow. The leaf size diminishes, the internodes are shortened, and a general stunting of the vegetative growth is apparent. The application of sulphur is the control measure.

**Insect pests**
The insects pests that attack tea in different parts of Africa are red spider mites, black tea thrips, red crevice mites and yellow tea mites.

**Red spider mites** (*Oligonychus coffeae*) are found on the upper side of the leaf in clusters showing all stages of development. They spin a fine web over the surface of the leaf and their sucking activity produces red spots. Cultural control is effected by the maintenance of shade and good cultural conditions, by pruning and by the cleaning out and defoliation of pruned tea.

**Black tea thrips** (*Heliothrips haemorrhoidalis*). This pest is also called the black greenhouse thrip. Its host range includes a wide variety of tropical fruit crops as well. In most situations, this pest usually causes only minor yield reductions in the tea crop.

**Red crevice mites**, or **scarlet mites** (*Brevipalpus phoenicis*) adhere densely to the underside of the leaf near the mid-rib and produce a brown scurfy discoloration.

**Yellow tea mites** (*Hemitarsonemus latus*) attack the young leaves and ruin the flush. Growth ceases and the leaves turn yellow.
COFFEE
(Coffea spp.)

The genus *Coffea* is a member of the family Rubiaceae. About 75% of the world’s coffee comes from the tetraploid species *Coffea arabica*, arabican or arabica coffee. It is a native of the wet highland forests of Ethiopia where it grows wild. The diploid species *C. canephora*, robusta coffee, is native to the rainforests of equatorial Africa. It accounts for 25% of world production and is used mostly to make powdered, instant coffee. Most of the robusta coffee is grown in Africa. A third species, the diploid *C. liberica*, liberica coffee, is indigenous to Liberia. It accounts for 1% of world production. The beverage made from liberica coffee is of poor quality.

Area and Production
The area and production of green coffee in the world during 1989 were 11.2 million hectares and 5.8 million tonnes, respectively. In the same year, the area and production of green coffee in Africa were 3.4 million hectares and 1.3 million tonnes, respectively. Maximum production comes from Brazil (about a quarter of world production). Other important coffee-producing countries are Colombia, Indonesia, Mexico, Côte d’Ivoire, Guatemala, India, Ethiopia, Uganda, the Philippines, Costa Rica, Ecuador, Kenya, Peru, Honduras, Zaire, Cameroon and Madagascar.

Origin and Distribution
The centre of origin of arabica coffee (*Coffea arabica* L.) is in Ethiopia where it grows wild in the forest. It was domesticated only recently compared with most other crops. It was cultivated, and a drink was first made from the roasted seeds, in Yemen (Middle East) during the fifteenth century AD, but when it reached there from Ethiopia is not known. From Yemen, it was introduced to India and Sri Lanka at the end of the seventeenth century, and very soon afterwards to Java (Indonesia). The subsequent history of this variety, *C. arabica* var. *arabica*, is truly remarkable. A single plant from Java was taken by the Dutch to Amsterdam in 1706 and from there, coffee was taken to Suriname in 1718, to the Philippines in 1740, and Hawaii in 1825. From Suriname it was taken to Brazil in 1727. By the middle of the eighteenth century coffee was spread throughout the Caribbean and Central and South America. The French introduced it to their African territories. Perhaps the French took it to Reunion in about 1718. It was introduced to Tanzania and Kenya at the end of the nineteenth century and it reached Uganda in 1900. Much later this variety became important in East Africa.
Robusta coffee (Coffea canephora Pierre ex Froehner) occurs wild in African equatorial forests from the west coast to Uganda, chiefly between 10° N and S. Local people used to plant this crop in small areas and also used to collect the seeds before the arrival of Europeans. The coffee of this area was named C. canephora by Pierre in 1897. Planting material was taken from the Congo to Belgium. From there it was sent to many botanical gardens in Europe. In 1900 it was introduced from Belgium to Java (Indonesia) where it proved very successful under the name of robusta coffee to distinguish it from arabica. In 1989 it was sent from Kew in the UK to Singapore and Trinidad. Since then, robusta coffee has been widely distributed throughout the tropics where it is grown successfully at lower elevations, which are unsuited to arabica. It is now the most important species in tropical Africa and Asia.

Adaptation

Coffea arabica is a tropical crop. It is grown as an understorey tree in forests at altitudes of 1,500–2,000 m. The ideal conditions for arabica coffee are mean temperatures of 16–24°C and an annual rainfall of about 1,500–2,250 mm which is well distributed, but with a drier period of 2–3 months for the initiation of the flower buds. These conditions are found in the equatorial belt. In low rainfall areas, coffee is grown with irrigation and heavy mulching.

C. canephora is not as specific in its requirements as C. arabica and shows a wider range of adaptability. It is best suited to lower altitudes and is grown from sea level to 1,500 m. Its requirements for temperature and rainfall are the same as for C. arabica but it is more tolerant of adverse conditions and poor management.

Both temperatures higher and lower than the optimum are not good for coffee. At temperatures above the optimum, forced rapid growth occurs causing too early bearing, overbearing and early exhaustion. At low temperatures the growth is slow and the trees are stunted and uneconomic. Low temperatures may also lead to a high production of secondary and tertiary vegetative branches. Periods of mist and low cloud are beneficial but strong winds are harmful.

The best soils for coffee are deep, well-drained, fertile loams of lateritic or volcanic origin with a reasonable humus content and slightly acidic (pH 5.3–6.0). Heavy loams and clays are unsuitable because they are poorly aerated; sandy soils are equally undesirable because they dry out rapidly.

Botanical Description

Coffea arabica is a small tree which grows up to 8 m tall if it is not pruned. The height is commonly controlled by careful pruning to
produce a more or less densely branched bush 2–3 m tall, though much coffee is grown without pruning.

The plant has a short, stout tap root, rarely extending beyond 45 cm deep. About 4–8 axial roots originate from the bottom of the tap root and grow almost vertically downwards to a depth of 2–3 m. The axial roots are fairly thick and branch profusely. A mass of ramifying lateral roots of 1–2 m long is formed. These are the main feeding roots and form a surface mat seldom deeper than 30 cm. Below these are the lower laterals which ramify evenly and more deeply in the soil.

There are two kinds of vegetative growth of branches: vertical growth and horizontal growth. Vertical growth type branches only produce further vegetative growth. Horizontal growth type branches can produce both reproductive growth and vegetative growth. Horizontal branches are called laterals.

Each node on a vertical growth branch, i.e. on stems and suckers, gives rise to opposite pairs of leaves. From each axil, two types of buds are formed. The upper bud develops and produces a lateral, while the lower bud remains dormant. On laterals the leaves are borne in opposite pairs and on a horizontal plane. In each axil, 3–5 buds are formed. Each bud is capable of developing into an inflorescence or sublateral but it cannot produce upright growth.

Each inflorescence usually consists of about four flowers, but not all four may develop. Flowering usually occurs in a flush and is stimulated by the onset of rains after a dry period of 2–3 months. In the absence of a dry period, there may be a small amount of flowering all the year round. The flowers are white and sweetly scented. Each flower produces one fruit normally containing two seeds which are called beans. Each of the two beans remains enclosed in a tough membrane called the parchment. A thin testa called the silverskin remains closely adhered to each bean. Fruit development is a long process and the ripening period, from flowering to maturity, is normally 8–9 months.

The seeds of *C. arabica* are 8.5–12.5 mm long (Fig. 71). The dried seeds, after removal of the silverskin, provide the coffee beans of commerce. Approximately 5–6 kg of cherry (whole fruit) provides about 1 kg of clean coffee bean and there are about 2,250 dried beans to the kilo. The seeds of *C. canephora* are about 8.5 mm long. The proportion of cherry to clean coffee bean is 4.5:1 and there are about 3,300 dried beans to the kilo. The flowers and fruit of *C. liberica* are the largest of all cultivated coffee. The seeds are 13 mm long. The proportion of cherry to dried coffee bean is 10:1 and there are about 1,750 dried beans to the kilo.
Cultivation

As *C. arabica* is the main species and accounts for about 75% of the total world production, the descriptions in the following pages relate to this species.

*Raising seedlings*

Coffee is usually propagated from seed, though it can be propagated vegetatively by budding, grafting or from stem cuttings. Seeds are collected from superior bushes. Light beans, pea-berry and large seeds are discarded. The seeds are sown in a nursery which should be prepared on level land with deep fertile soil and be near a source of water. The nursery beds should be dug deeply. The bed should be raised, 1.2 m wide and of any convenient length. Arrangements for shade must be made before sowing. Seeds are sown either thickly
with the intention of transplanting the seedlings at the cotyledon stage, again in the nursery, or thinly so that the seedlings are left undisturbed until they are ready to be transplanted directly to the field. Seedlings may also be raised in seed-boxes or polythene bags. Germination takes place in 4–8 weeks and seedlings are transplanted in the field at the 6-leaf stage, when 6–18 months old. Weak seedlings should be discarded.

Transplanting in the field
The land should be prepared well in advance of transplanting. All vegetation should be removed from the field and the planting holes should be dug at least 3 months before transplanting. They should be 0.6 m square and 0.6 m deep and be dug in straight rows at an inter-row space of 2.7 m and an intra-row space of 1.4 m. Planting at this spacing (2.7 × 1.4 m) will give 2,660 plants per hectare. This closer spacing is recommended only where there is an assured supply of nutrients and moisture. If this is not the case, wider spacings (3.0 × 2.4 m) are recommended. About 2–3 weeks before transplanting, the top soil of each planting hole is taken out and mixed with manure and 30 g of superphosphate. The holes are then refilled with this mixture and additional top soil if necessary.

Transplanting is done at the beginning of the rainy season. The holes are reopened immediately before transplanting. The seedlings should be carefully uprooted so that they carry some soil around their roots. Transplanting should also be done carefully so that the roots are not bent. Soon after transplanting, mulch should be placed around the seedlings. Covering the seedlings with banana leaves after transplanting is also beneficial.

Maintenance
Young coffee can be intercropped with beans, cowpeas or groundnuts during the first two years without much disadvantage. All blanks in the field should be filled in as quickly as possible. Mulching is very beneficial partcularly in areas with low rainfall and should be applied before the onset of rains. A thick layer (10 cm) of dry grass forms a good mulch.

Fertilization
In Africa, nitrogen is the main element that is applied to coffee, although in other countries compound fertilizers containing N, P and K are applied. The amount of nitrogen to be applied depends on the anticipated yield of the crop and varies from 80–140 kg/ha per year. The nitrate form of nitrogen is preferred to the ammonical form. The full dose of nitrogen may either be applied only once or in
three splits: the first at the beginning of the long rains, the second a month later and the third during the short rains.

Before applying fertilizer, all mulch should be removed. In young coffee, fertilizer can be spread in a ring around, but not very near to, each plant. In mature coffee, fertilizer is usually spread in a band along the inter-rows.

Water use
In high rainfall areas, irrigation is seldom used. Some of the lower coffee estates in Kenya and Tanzania use overhead irrigation during the dry season.

Weed control
With its shallow feeder roots, coffee is highly intolerant of competition with weeds and good weed control is therefore essential. Many annual broadleaved weeds are common in coffee fields, but the most damaging are the perennial grasses such as couch grass (*Digitaria scalarum*), star grass (*Cynodon dactylon*) and sedges (*Cyperus spp.*). These are very difficult to eradicate.

If the land is bare, i.e. without any inter-crop or mulch, continuous cultivation keeps the weeds under control. This can be done with hand tools. Sometimes herbicides are used but they have usually failed to control the grasses.

When the coffee plants are young, the directed application of paraquat may be very effective in controlling weeds. In established coffee, simazine and diuron at 3 kg/ha, or fluometuron and linuron may be applied, mixed with paraquat.

Pruning
Like most fruit trees, the coffee tree has a marked tendency to bear biennially, i.e. to produce a heavy crop in one season and a light crop in the next. Berries are borne on second-season wood, i.e. on nodes which were formed in the previous season. The aim of pruning is to provide a plentiful supply of healthy, leafy wood on which the following season's crop will be borne, to maintain the correct balance between leaf area and crop, to prevent overbearing and to reduce or eliminate biennial bearing.

The coffee tree, if left unchecked, will grow as high as 8 m and can then only be harvested with difficulty. It is therefore essential to limit the height of the tree by pruning. Pruning consists of topping to a desired height and removing all the weak and dead branches and all types of surplus fruiting branches and suckers. Pruning prevents primary branches from growing too long and spindly and replaces them where necessary with strong secondaries. The best time to
prune is in the dormant period after harvesting and before the new flush of growth begins.

Two systems of pruning are employed, single-stem pruning and multiple-stem pruning. The aim of single-stem pruning is to have one permanent stem, capped to 1.5–1.8 m above ground level with a permanent framework of laterals. The crop is borne on sub-laterals. In this system of pruning the stem is capped (i.e. taken off) by 15 cm at knee, waist and chest height, permitting only one of the axillary branches to develop at each capping, and finally stopping growth at 1.5–1.8 m.

Multiple-stem pruning consists of topping to encourage the growth of two or more main stems which are replaced by selected suckers every 4–6 years. The crop is borne mainly on laterals. Each lateral bears two crops and is then removed; crops are therefore higher and higher up the stems in successive years. As the lower primaries become exhausted they are cut away and eventually a new sucker may be allowed to grow by cutting back the unproductive upright. This method is easier and cheaper than single-stem pruning and is now extensively practised.

**Harvesting**
Coffee trees come into bearing 3–4 years after transplanting, are in full bearing at 6–8 years and may continue to bear for 50–60 years. The fruit matures 7–9 months after flowering. The fruits are collected by hand when they are mature, either by direct picking from the branches or after they have been shaken to the ground. Only uniformly ripe berries can produce good-quality coffee. The entire surface of a ripe berry is red. Over-ripe berries (dark) and under-ripe berries (green) are no good. Berries of mixed ripeness cause uneven fermentation. As all the berries do not ripen at the same time, several pickings at 10–14 day intervals are needed. Harvesting continues over a period of several weeks.

**Processing**
There are two methods of processing, the dry method and the wet method. In the dry method the mature berries are spread out thinly and dried in the sun without being pulped for about 15–25 days. Then they are hulled. Coffee beans processed in this way are inferior to those subjected to wet processing. Most of Brazil’s coffee is prepared in this way.

In the wet method, the mesocarp of the berries is removed in a pulping machine soon after picking (not longer than 24 hours after picking, or they begin to ferment). Under- and over-ripe fruits are processed separately. After pulping, the seeds are washed and then
passed on to the fermenting tank for about 12–24 hours. During fermentation the remains of the mesocarp and the mucilage which surrounds the parchment are removed and the desirable, bright, greyish-blue colour of the seed is developed. The seeds are then dried on racks in the sun for a week or more, during which they are turned regularly and protected from rain. Finally the dried beans are hulled by a machine which removes the parchment. They are then polished to remove the silver skin. In Africa, this is the only method of processing used.

Processed dried coffee beans contain approximately 12% water, 35% cellulose, 14% protein, 10–13% oil (including the volatile oil cafféol which is largely responsible for the distinctive aroma of the beverage), 7–10% sugar and 1.5% cafféins. The flavour and aroma of coffee are accentuated when the beans are roasted. They are ground and used soon after roasting because the grounds loose their flavour and the oils in them become rancid when they are kept.

**Yields**
The turn-out of clean dry coffee from ripe cherry is 15–20%. Average yields of clean coffee beans vary between countries and estates. The average yield in Brazil is about 500 kg/ha and the average yield in East Africa is about 900 kg/ha. In Kenya a few estates have yielded up to 2,000 kg/ha.

**Crop Protection**

**Diseases**
The important diseases that attack coffee in Africa are coffee berry disease, Elgon die-back and leaf rust.

**Coffee berry disease**, caused by *Colletotrichum coffeaeum*, causes serious losses in many African countries. The strain which is parasitic attacks the berries in the green stage, causing brown sunken spots. Badly affected berries go completely brown to black, and the beans inside are destroyed. The disease is controlled by fungicides applied at flowering and early fruiting.

**Elgon die-back**, also caused by *Colletotrichum coffeaeum*: the first symptom is blackening of the node and petiole, followed by the death of the branch above the node. The use of resistant varieties and regular spraying with fungicides gives some reduction of the disease.

**Leaf rust**, caused by *Hemileia vastatrix*, is most serious at low altitudes and when trees are weakened by overbearing. First of all yellow spots appear on the leaves. These enlarge rapidly, forming circular lesions which have orange pustules on the lower surface; later defoliation occurs. Some resistant strains are now available.
Spraying with copper fungicides is beneficial and they are most effective when sprayed at the start of the rains.

**Insect pests**

In Africa coffee is attacked by more insect pests than in other parts of the world. The most damaging pests are leaf miners, coffee bugs, cherry borers and mealy bugs.

**Leaf miners** (*Leucocera meyrichi* and *L. caffeina*): the eggs are laid on the upper surface of the leaves. Upon hatching the larvae bore into the leaf and defoliation occurs. Repeated spraying with recommended insecticides keeps the pest under control.

**Coffee bugs** (*Antestiopsis orbitalis*) suck young berries and feed on the flowers. If no fruit or flowers are present they feed on the growing points. Pyrethrum, malathion or any other recommended insecticide can be sprayed to control this pest.

**Cherry borers** (*Stephanodera coffea*) cause serious damage as the adults bore into the seeds, where they breed, and their larvae continue burrowing.

**Mealy bugs** (*Plannococcus kenyae*) form a white mealy mass around flower clusters, fruits and growing tips. Banding the trees with dieldrin has been found to be effective in controlling the bugs.
COCOA
(Theobroma cacao L.)

The word 'cacao' is often used for the tree and its parts and the word 'cocoa' for the manufactured product. However, in this book the word cocoa is used both for the tree and the products. American Indians believed that cocoa was of divine origin, hence the generic name *Theobroma*, meaning the food of the gods, given by Linnaeus.

**Origin and Distribution**
Cocoa has been cultivated for centuries in Central America and the northern part of South America. Cocoa presumably originated in the equatorial rain forests to the east of the Andes Mountains in South America, where a wide range of types now grow in the dense shade cast by tall forest trees. Cocoa was an early introduction into Mexico where the potential of the crop was fully realized. After the arrival of the Spaniards, cocoa spread rapidly into New World countries such as Venezuela, Trinidad, Jamaica, Haiti and Brazil, during the sixteenth century. The Spanish and Portuguese introduced cocoa to islands in the Gulf of Guinea in the seventeenth century and from there it spread to many West African countries. In the seventeenth century it was also introduced to South-East Asia. The Germans took it to New Guinea and it was introduced to Uganda in 1901.

**Area and Production**
The area and production of cocoa in the world during 1989 were 5.3 million hectares and 2.5 million tonnes, respectively. Africa is the leading continent for cocoa production, accounting for more than half of the world output. The area and production of cocoa in Africa in 1989 were 3.4 million hectares and 1.4 million tonnes, respectively. Cocoa is mainly grown in Côte d'Ivoire, Brazil, Ghana, Malaysia, Nigeria, Cameroon, Indonesia, Equador, Colombia, Mexico, the Dominican Republic and Papua New Guinea.

**Utilization**
The dried beans contain 0.7% sugar, 7.4% starch, 1.7% theobromine, 6.7% protein and 50–57% of the pale yellow, non-drying fat known as cocoa butter. For the manufacture of chocolate, the beans are shelled, roasted and ground to a mass to which extra cocoa butter, sugar and other ingredients are added. The residue of the beans from which the cocoa butter has been expressed provides, after processing, the cocoa powder using for making the beverage and for flavouring.
Adaptation
Cocoa is a purely tropical crop, restricted in cultivation to lowland areas. The limits of cultivation are 20°N and S, but the bulk of the crop is grown within 10°N and S. It usually grows in groups along river banks, where it may often stand in water for 6 months, provided it is running water to supply the necessary oxygen. It is mainly grown at low elevations, usually below 300 m, but is cultivated at 1,000–1,200 m in Venezuela and Colombia. It is grown in areas of high rainfall (around 2,000 mm per year), well distributed throughout the year. The optimum temperature range is 21–32°C, with a small seasonal and diurnal range. It can tolerate periods of little rainfall provided that it is grown on soils with a large water-holding capacity. It does not tolerate sudden changes in humidity. Cocoa can survive in dense shade which would kill many other species, but it can also survive considerable exposure to the sun.

Cocoa requires a well-drained deep soil with a good crumb structure. The soil may be sandy loam, loam or clay, provided it has a large water-holding capacity. The optimum soil pH is around 6.5

Botanical Description
Cocoa is a small under-storey tree 6–8 m high. It has a strong tap root with lateral branches which produce a mat of fibrous feeding roots extending several metres around the tree in the surface soil. The cocoa tree has two kinds of branches; an upright type, such as the main stem or sucker, which is called a ‘chupon’, and the fan or ‘jorquette’ which produces 3–5 branches fanning out 90–150 cm above the ground and forming the canopy. When the main stem has grown to about 1.5 m, 3–5 horizontal branches (jorquettes) are produced. As the jorquettes develop, a new leading shoot (chupon) grows vertically from an axillary bud below the apex of the main stem, and in turn produces jorquettes above the first. This branching pattern is repeated until the tree develops to a height of 6–8 m.

Spirally arranged, long (about 30 cm) oval leaves with pointed tips are formed on the main stem or chupon, and alternately in two horizontal rows on the jorquettes. Numerous groups of small flowers arise directly from the bark of the main trunk and older leafless branches. The clusters of flowers grow from small cushions which are greatly modified branches growing from the axils of very small, sessile leaves. Although one cushion may produce many flowers, only one or two develop into fruits. The flowers are pollinated by flying insects and if they are not fertilized within 24 hours of opening they wither and fall. It has been found that only 1 in 500
flowers produces a mature fruit, largely because of very poor pollination, but also because nutritional or physiological disturbances cause some of the young fruits to shrivel and shed.

The cocoa tree begins to bear fruit when it is 4–5 years old and continues to do so for 50 years or more. The fruits ripen 5–6 months after flowering and each fruit contains 20–60 seeds embedded in a mass of white or pink pulp developed from the outer layer of the testa. The mature seed is about 3 cm long and up to 2 cm broad. The indehiscent fruit is called a pod. The pods are up to 30 cm long and 10 cm in diameter. The seeds constitute about 25% of the weight of the mature pod.

Cultivation

Propagation

Cocoa is propagated either from seed or from cuttings. Propagation from seed is a very common method. The seeds should be chosen from the healthiest and highest yielding trees. Soon after removal from the pods, the seeds should be washed, dried in the shade, and planted, otherwise viability will be lost.

The seeds may be planted in nurseries or next to stakes in the field. When sown next to stakes, three seeds are planted per hole and the seedlings are later thinned to one, leaving only the healthiest. Where stake planting is practised in Nigeria, the seeds are planted 1.2 × 1.2 m apart and later thinned to 2.4 × 2.4 m as the tree begins to bear, thus ensuring a good canopy. In Ghana, planting is done at 3 × 3 m apart.

Nurseries should be near a stream or another source of water. The beds should be provided with natural or artificial shade. The seeds are usually planted 30 cm apart in the beds but in Ghana, much closer spacing is practised. Seedlings may also be raised in baskets 25 cm deep and 18–22 cm wide at the top and 15–17 cm at the base. Seedlings in baskets should also be raised in the shade. The seedlings should be watered regularly. The seedlings are planted out when they are 30–60 cm high. Only the sturdiest, healthy plants with fully developed leaves at the growing point (apex) should be chosen. Before transplanting the seedlings, large and deep holes are made at the spacings given above and the top soil and subsoil are heaped separately next to each hole. A few days before planting, some manure is mixed with both the top soil and the subsoil and these are put back in the hole in the right order. Care should be taken that the roots of the seedlings have enough soil around them when they are transferred from the nursery to the field. When the seedlings have been transplanted, the soil should be pressed firmly about the roots. Transplanting should only be done during wet weather.
Shade
It is usually considered essential to provide shade to cocoa from planting until it becomes self-shading or permanent overhead shade has been established, but when grown under very favourable conditions (i.e. on fertile, deep, well-drained soil and with liberal applications of fertilizer) shade is not essential and need only be provided in the early stages of growth. This can be done by intercropping with plantain, cassava, dasheen, pigeon pea or tree cassava (Manihot glaziovii). Permanent shade may be provided by selective thinning of the original forest or by interplanting the cocoa with other economic trees or specially planted shade trees which are planted before or at the same time as the cocoa. Cocoa is occasionally intercropped with bananas, oil palm, rubber or coconuts.

Fertilization
When cocoa is grown under shade it is seldom fertilized. The shade trees and shrubs, and also the cocoa trees themselves, contribute a considerable amount of nitrogen to the soil by providing a good litter from their fallen leaves. The litter not only provides nitrogen to the soil but also improves the physical condition of the soil. Under shade, however, the application of phosphate can increase yields.

When grown under favourable conditions with no shade, the application of nitrogen gives spectacular results. Besides nitrogen, phosphorus and potassium have also been found useful in increasing the yield of cocoa. To obtain optimum and continuous high yields, annual dressing with 60–80 kg N, 30–40 kg P₂O₅, and 100–200 kg K₂O/ha may be recommended.

Maintenance
All gaps in the stand of cocoa and permanent shade should be filled in as soon as possible. Ground shade (planted to protect the soil and provide temporary lateral shade) should be removed in the third year. Temporary overhead shade such as bananas should be gradually removed in the fourth year after planting cocoa.

Weed control
Weed control is essential in the early growth stage. The weeds may be controlled by cutlassing, but before doing so the area around the seedlings should be hand weeded to ensure that they can be seen when cutlassing.

Harvesting
Pods are produced throughout the year. The main harvest begins at the end of the wet season and lasts from October to January, and a
minor harvest begins early in the rainy season and lasts from April to June. Only fully ripe pods should be harvested so harvesting continues for three to four months. Fully ripe pods sound hollow when tapped. The pods remain in a suitable condition for harvesting for 2–3 weeks. Unripe pods contain too little sugar for fermentation, while over-ripe pods may dry and germinate in the pod, so picking only the ripe pods once every 3–4 weeks ensures more and better quality cocoa. Pods should be cut from the tree with a sharp knife or cutlass, while those out of reach are cut with a hooked knife attached to a pole. During harvesting, care must be taken that the cushion is not damaged as it may then stop bearing. After harvesting, the pods are broken with wooden mallets, or by knocking two pods together, so separating the seeds from the pods. Unripe, diseased, damaged or germinated seeds should be discarded.

**Processing**
The seeds constitute about 25% of the weight of the mature fruit and are removed after splitting the pericarp. The processing of the seeds consists of fermentation, drying and polishing.

**Fermentation**: in West Africa, cocoa is fermented in heaps or in baskets usually covered with banana leaves. In other countries, fermentation is done in wooden sweat boxes. Before heaping the seeds, arrangements are made for draining off the by-products of fermentation. For this either two layers of banana leaves are spread on the ground, or a layer of sticks of uniform thickness is first put underneath the heap. The heaps are covered by banana leaves and allowed to ferment for up to one week, during which time they may be stirred on the third and fifth day to allow good aeration and to prevent the temperature from rising above 50°C.

The beans can also be fermented in a set of three wooden boxes, each 90 cm long, 105 cm wide and 60–90 cm deep, raised from the ground, with drainage holes at the bottom. The boxes are arranged side by side but on tiers at three levels. The beans are put in the highest box and covered with banana leaves. There is a removable panel at the side of each box so that when the beans are turned over they can be pushed into the middle box and finally into the bottom box.

Fermentation is also done in trays of 90 × 120 cm and 10 cm deep with slatted bottoms. These are stacked to a depth of 10 trays and covered with sacking. With this method, beans are fermented in three days without any turning and the same trays can be used for drying the beans.

During fermentation sugars in the pulp are broken down by yeasts so that the pulp and mucilage disintegrate into a vinegary
fluid which escapes through the slats or holes in the box. During the process the embryo is killed, various chemical changes occur in the beans, and the flavour and aroma of cocoa develop. The colour of the purple cotyledons changes gradually until, in well-fermented beans, the tissues are pale brown. When the temperature of the mass has come down to 35°C the fermentation process is considered to be complete.

**Drying and polishing:** After fermentation the beans are dried in the sun by spreading them on mats, in trays, or on the floor. They are covered by mats or movable roofs to protect them from rain, dew, or excessive heating by the sun. The beans are stirred to ensure uniform drying and in sunny weather this stage is completed in about 7 days. During drying, the moisture content of the beans drops from about 50–60% to about 6%. In some countries, artificial driers are used. 100 kg of wet beans give 40 kg of dry beans. The beans may be polished mechanically or by wetting them and trampling on them with bare feet. The dried and polished beans are packed into jute bags for transport to the factory.

**Yields**
In West Africa, yields vary between 200 and 1,000 kg of dry beans/ha and the average yield is about 600 kg/ha. In other parts of the world, yields of up to 2,000 kg/ha under shade, and more than that when unshaded but fertilized, have been obtained. It takes 16–30 kg of pods to produce 1 kg of dry cocoa.

**Crop Protection**

**Diseases**
Cocoa can be attacked by black pod, mealy pod, warty pod and swollen shoot.

**Black pod**, caused by *Phytophthora palmivora*, is the most widely distributed disease of cocoa. A brown spot appears on the pod and the destruction of the pod tissues spreads rapidly until the whole pod, including the beans, is affected. Two days after a spot has appeared, a white down is seen on the surface of the pod. Regular and frequent harvesting and the removal of infected pods reduces losses. Spraying with copper fungicide every three weeks throughout the rainy season has been found effective in controlling the disease. Recommended fungicides include Perenox (copper oxide), lime-bordeaux mixture and carbide-bordeaux mixture.

**Mealy pod**, caused by *Trachysphaera fructicena*, attacks coffee and cocoa. It attacks pods that have suffered mechanical damage either by catlass or other means. First a brown spot appears which
develops and destroys the pods in the same way as black pod disease.

**Warty pod**, caused by *Botrydiplodia theobromae* attacks only damaged pods. The pods usually show lumps of a lighter green colour than normal. These pods turn black as they ripen and become rotten, with water oozing from the swellings as they burst.

**Swollen shoot** is a virus disease. Many strains of the virus are found but not all the strains produce swollen shoots or root swelling. Control is by burning infected trees and by the use of resistant cultivars.

**Insect pests**
The main insect pests of cocoa are mealy bugs and capsids.

**Mealybugs**: the swollen shoot virus is transmitted by mealybugs. Some mealybugs are found in the hollow pith of the trees along with certain black ants. The ants make a ‘tent’ or mud cover on the cocoa shoots over the mealybugs. To destroy the mealybugs it is better to destroy the ants first. When the ants are killed the mealybugs will themselves die.

**Capsids** are the most damaging insect pest of cocoa in Ghana. Two species of capsid cause damage to cocoa, *Distantiella theobromae* (black capsid) and *Shalbergella singularis* (brown capsid). They feed on pods and young shoots. *D. theobromae* prefers young seedlings and *S. singularis* mature trees. A severe attack quickly kills the shoots and leaves.
18

LATEX CROPS

Natural rubber accumulates as an excretory product in colloidal suspension in the latex produced by some plants. The production of latex is a characteristic feature of many plants, but latex containing rubber in large quantities occurs only in species of the families Moraceae, Euphorbiaceae, Apocynaceae and Compositae. Latex accumulates in the laticifers (latex tubes) under pressure and flows from them when they are cut.

Rubber is obtained from many plant species, the most important of which are:

* Hevea brasiliensis of the family Euphorbiaceae
* Castilla elastica of the family Moraceae
* Manihot glazovii of the family Euphorbiaceae
* Parthenium argentatum of the family Compositae
* Taraxacum kok-saghyz of the family Compositae
* Ficus elastica of the family Moraceae
* Funtumia elastica of the family Apocynaceae.

The last is a West African wild plant.
PARA RUBBER

(Hevea braziliensis (Willd. ex Adr. de Juss) Muell Arg)

Para rubber is the primary source of the world’s natural rubber and has become increasingly important since the beginning of the twentieth century.

Origin and Distribution
Para rubber originated in Brazil in the tropical rain forest of the Amazon basin. In the beginning of the nineteenth century, small quantities of rubber reached Europe from the Para area. During the 1870s many attempts were made to establish a rubber industry in the Indian sub-continent by the British. H. A. Wickham’s attempt was successful. He collected 70,000 seeds of H. braziliensis and sent them to the Royal Botanical Gardens in Kew, England, where they were planted. Only a small proportion of them germinated. From Kew, some young plants were sent to Sri Lanka, Singapore and Java. Today, South-East Asia is the main centre of para rubber production.

Para rubber was introduced to various tropical African countries early in the twentieth century. The first seedling from Kew was sent to Uganda in 1901. Uganda also obtained some seeds from Sri Lanka in 1903. After a few years, it was introduced to Nigeria which is now the second largest producer in Africa. In 1924 the Firestone Tyre and Rubber Company began plantations in Liberia, which is now the largest producer in Africa.

Area and Production
The annual world production of para rubber in 1989 was 4.8 million tonnes. Almost 90% of it came from Malaysia, Indonesia, Thailand, India, China, the Philippines and Sri Lanka. Malaysia accounts for about 30% of total world production. The continent of Africa supplies about 6% of the world’s rubber. Liberia, Nigeria, Côte d’Ivoire, Cameroon and Zaire are important African countries for rubber production.

Utilization
The latex of rubber plants consists of a colloidal suspension of rubber particles in an aqueous serum. Natural rubber is an amorphous hydrocarbon, polyisoprene \([\text{C}_4\text{H}_8\text{Ln}]\), which has the property of being highly extensible. The latex also contains many non-rubber constituents, such as proteins, resins, sugars, glucosides, tannins, alkaloids and mineral salts.

The kernels, which constitute 50–60% of the seed, contain
40–50% of a semi-drying oil used for making soap. The cake left after oil production contains about 30% protein.

Thousands of different products are made from rubber. More than 70% of the total rubber consumption is in the manufacture of tyres and tubes and other items associated with automotive transport. About 6% is used for footwear and 4% for wire and cable insulation.

Adaptation
Most planted para rubber is grown between 15°N and 10°S where the climax vegetation is lowland tropical forest and where the climate is hot and humid with temperatures ranging from 23–45°C with a well-distributed rainfall of 1,800–2,000 mm or more per annum. As rubber produces continual flushes of new leaves, a fairly even distribution of rainfall throughout the year is preferable to heavy rainfall over a short period followed by a long dry season.

Although the crop will tolerate a wide range of soils, it does best on deep, well-drained loams. Shallow, poorly-drained or peaty soils are not good for para rubber. It can be grown on a wide range of soil pH, varying from 4–8, but the optimum range is pH 5–6.

Botanical Description
Hevea braziliensis belongs to the family Euphorbiaceae. It is a tree which commonly grows up to 25 m tall with a straight trunk covered with smooth, light-grey bark 6–15 mm thick. The tree has a deep tap root with lateral roots 7–10 m long. Slender branches form an open, leafy crown, with spirally arranged trifoliate leaves. Three extra-floral nectaries occur at the junction of the leaflets with the petioles. These nectaries only secrete nectar on the new flush during flowering. The tree grows in flushes. The inflorescence of para rubber is a short axillary panicle with hairy branches. The larger female flowers are at the terminal ends of the inflorescence branches, while the many male flowers occur near the base. For each female flower in the inflorescence there may be as many as 80 males. The flowers mature over a period of 2 weeks, during which time some of the male flowers open first, then the females, and then the rest of the males. Pollination is by insects. Only a small proportion of female flowers set fruit. Of these 30–50% fall off after a month and some more fall of later. The fruit ripens about 5–6 months after fertilization. It is a large, deeply three-lobed capsule, 3–5 cm in diameter, with one seed per carpel. It dehisces explosively. The seeds are large, ovoid, shiny, 2–3.5 cm long and 1.5–3 cm broad (Fig. 72). They lose their viability soon after they are mature. The seeds are
poisonous because they contain a cyanogenetic glucoside, although this can be removed by boiling them in water.

Cultivation

Propagation

Propagation of para rubber can be done from seed and by budding. The seeds may be planted next to a stake, usually two or more seeds per hole at $4 \times 4.2$ m spacing, and the seedlings are later thinned to one per stake. The seeds may also be planted in nurseries. Seeds remain viable for only a month after they mature, so they should be sown soon after harvesting. For nursery plantings, seeds are germinated in shaded beds. The seeds are pressed closely on the surface of the beds, covered up with sacking, and watered daily. Germination starts from 4–5 days after sowing and is completed in about three weeks. Germinated seeds are removed daily after the fifth day and planted in shaded nurseries at spacings of $30 \times 30$ cm or $45 \times 20$ cm. After 10–15 months, the entire plant is pulled or dug out of the ground. The stem is cut back to 45–60 cm of brown bark, the tap root is pruned to 45–60 cm and the side roots to 10 cm. The seedlings stumps are then tied into bundles, transported to the field and transplanted.

Modern plantation rubber is propagated vegetatively by budding scions from selected, high-yielding trees onto vigorous root stock (seedlings) to establish high-yielding clones. The stocks are grown in nurseries and budded at 12–18 months as near the ground as possible. Two parallel cuts are made and the latex that exudes is removed before cutting the panel at the top and inserting the scion. The bark panel on the stock is pulled over the scion (bud) and bound tightly. It is left for about three weeks to allow the cambiums of the stock and bud-wood to unite. After this period, the flap is removed and after two weeks the stock may be topped to force the bud to grow. The budded stumps are then dug up and the cut ends dipped
in hot wax to seal them. The budded stumps are then carried to the field for transplanting.

Transplanting
All trees should be cut and removed from the land where the rubber plantation is to be sited. All tree stumps should be removed and planting holes are dug at the selected spacing. The optimum density is 250–300 trees per hectare. To obtain this density 375–450 budding or 500–600 seedlings per hectare are planted, and later thinned out. The planting distance for square plantings may be $4.5 \times 4.8$ m for budding and $3.9 \times 4.2$ m for seedlings. In rectangular plantings, spacings of $9 \times 2.4$ m for budding and $8 \times 1.8$ m for seedlings are used.

Fertilization
Rubber responds to applications of nitrogen and also magnesium, because at most places a magnesium deficiency has been found. For the first few years a liberal dose of N and Mg may be applied. A heavy dose of rock phosphate may be applied in the very first year of transplanting.

Maintenance
Intercropping can be practiced during the first 2–3 years, provided the crop is not too near the line of rubber plants. On poor soils, the planting of a leguminous cover crop is advised. Young plants should be staked and the side shoots removed. Weeds should be kept slashed. Any young volunteer rubber seedlings appearing in the plantation should be removed.

Tapping
Tapping is the gathering of the latex. The latex occurs in articulated latex vessels derived from the cambium in a series of cylinders which alternate with the cylinders of phloem tissue. The number of such cylinders varies from two in the bark of young seedling trees to as many as 50 in the thick bark of old trees. They are closest together near the cambium, and consequently this part of the bark yields the greatest quantity of latex if the tapping incision is made deep enough to cut them.

The pattern of tapping incision is usually a half-spiral from the upper left to the lower right of the trunk at an angle of about 30° (Fig. 73). Only half the girth of a tree is usually tapped at one time. The incision is made with a knife with a V-shaped cutting edge so that a grooved channel is formed along which the latex can flow into the collecting cup. Latex flows most freely in the early morning. The
first tapping is done when the trees are 4–7 years old. After the initial incision has been made in the bark of a tree the same cut is renewed daily or on alternate days by removing a slice of bark about 1–1.5 mm thick. If the cambium has not been extensively damaged during tapping, a smooth layer of new bark grows over the wound and in 7–12 years the same area can be tapped again. Each morning the tappers collect the latex from the collection cups, as well as that which has coagulated in the previous day’s tapping channel.

**Processing**

It is necessary to ensure cleanliness during the gathering and processing of the latex, as pieces of bark or dirt spoil the appearance and decrease the quality of the rubber. After collecting the latex it should be sent to the factory immediately, where it is bulked and strained. The dry rubber content of latex is about 30–35%. For preparing smoked sheet rubber the latex is diluted with water to a 12–15% dry rubber content. It is then coagulated in a coagulation
tank by thoroughly mixing in acetic or formic acid. The rubber coagulates as a white spongy mass which is then passed between rollers to squeeze out the watery latex, after which the strips of rubber are dried and smoked in a curing house.

For many of the modern uses of rubber, or for the sale of concentrated (centrifuged) latex, care must be taken that no natural coagulation takes place during the collection of the latex. To avoid this, collection should not be delayed. If coagulation has taken place, more acid is added in the coagulating tank. Crepe rubber is produced by passing coagulated rubber through special rollers which rotate at unequal speeds and so have a tearing action. Crepe rubber is dried with controlled heat but not smoked. The rubber is graded and packed in bales for export.

Yields
There is a great variation in yields because of differences in planting materials and standards of cultivation. The average yield of unselected seedling rubber varies from 300–400 kg dry rubber per hectare. Budded clones give higher yields. Purseglove (1972) has reported that modern clones yield approximately 600 kg/ha in the first year of tapping, 1,000 kg/ha in the second year, 1,300 kg/ha in the third year, 1,400 kg/ha in the fourth year and 1,500 kg/ha in the fifth year.

Crop Protection

Diseases
In Africa, rubber is relatively little affected by diseases. The following diseases are found in other areas.

South American leaf blight, caused by Dothidella uliei, is one of the most serious diseases in South and Central America and Trinidad.

Powdery mildew, caused by Oidium hevea is serious in Sri Lanka.

Black stripe and leaf blight, caused by Phytophthora palmivora, are serious in India and Central America.

Mouldy rot, caused by Corticium fimbriata, pink disease, caused by Corticium salmonicolor, and white root rot, caused by Fomes lignosus are other diseases of rubber.

Pests
Termites, rats, squirrels, elephants and wild pigs may cause damage to the bark and trunk, particularly in young trees.
REFERENCES AND BIBLIOGRAPHY


Index

Actinomycetes 42
Adu 16
Africa 2000 Report 12
Air Content of Soil 36
Alfisols 31
Alkaline Parent Materials 39
Alkalinity of Soils 39
Allelochemicals 144
Aluminium 39
Amide Fertilizers 64
Aminization 43
Ammonia Volatilization 44
Ammonification 43
Ammonium Fertilizers 64
Annual Rainfall 25, 26
Appropriate Seeding Rate 136
Arible Cropping 103
Arid and Semi-Arid Regions 53
Aridisols 31
Atmospheric Humidity 20
Atmospheric Nitrogen 42
Availability of Labour and Equipment 141
Bacteria 44
Autotrophic Bacteria 42
Barley 225
Adaptation 226
Area and Production 225
Botanical Description 227
Crop Protection 231
Cropping Systems 228
Cultivation 226
Diseases 231
Fertilization 229
Harvesting and Threshing 230
Insect Pests 231
Land Preparation 229
Origin and Distribution 225
Sowing 229
Spikeslets 228
Types of Barley 227
Utilization 225
Water Use 229
Weed Control 230
Yields 230
Beans (Common, Field) 299
Adaptation 300
Area and Production 299
Botanical Description 300
Crop Protection 303
Cropping Systems 301
Cultivation 301
Diseases 303
Harvesting and Threshing 303
Insect Pests 304
Land Preparation 302
Origin and Distribution 302
Sowing 302
Utilization 299
Water Use 302
Weed Control 302
Yields 303
Beverage Crops 9, 429
Biotic Factors 41
Blue-Green Algae 42, 45
Booting 87
Border Strip 89
Broadcasting 137
Bubils 132
Buffering Capacity 41
Bulky Density 35
Bulky Organic Manures 60
Bulldozers 122
Bulksh Millet 191
Bush-Burning 104
Bush-Fallow 105
Bush-Fallow Period 106
Caffeine 429
Canopy Structure of the Crop 146
Cassava 233
Adaptation 236
Area and Production 233
Botanical Description 237
Crop Protection 247
Cropping Systems 240
Cultivation 240
Diseases 247
Fertilization 245
General Morphology of Tuber 238
Growth Cycle 240
Harvesting 246, 247
Insect Pests 249
Land Preparation 241
Origin and Distribution 233
Placement of the Cuttings 243
Planting Material 243
Procure 234
Propagation 242
Time of Planting 245
Tubers 239
Utilization 234
Gari 235
Flour 236
Leaves 236
Meal 236
Tubers 236
Weed Control 246
Yields 247
Castor 359
Adaptation 360
Area and Production 359
Botanical Description 360
Crop Protection 362
Cultivation 361
Diseases 362
<table>
<thead>
<tr>
<th>Index Entry</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harvesting</td>
<td>444</td>
</tr>
<tr>
<td>Insect Pests</td>
<td>446</td>
</tr>
<tr>
<td>Maintenance</td>
<td>442</td>
</tr>
<tr>
<td>Origin and Distribution</td>
<td>438</td>
</tr>
<tr>
<td>Processing</td>
<td>444</td>
</tr>
<tr>
<td>Pruning</td>
<td>443</td>
</tr>
<tr>
<td>Raising Seedlings</td>
<td>441</td>
</tr>
<tr>
<td>Transplanting in the Field</td>
<td>442</td>
</tr>
<tr>
<td>Water Use</td>
<td>443</td>
</tr>
<tr>
<td>Weed Control</td>
<td>443</td>
</tr>
<tr>
<td>Yields</td>
<td>445</td>
</tr>
<tr>
<td>Coleoptile</td>
<td>138</td>
</tr>
<tr>
<td>Commercial Fertilizers</td>
<td>63</td>
</tr>
<tr>
<td>Commission for Technical Cooperation in Africa</td>
<td>29</td>
</tr>
<tr>
<td>Common Diseases of Maize</td>
<td>173</td>
</tr>
<tr>
<td>Common Weeds</td>
<td>145</td>
</tr>
<tr>
<td>Compost</td>
<td>61</td>
</tr>
<tr>
<td>Compound Fertilizers</td>
<td>70</td>
</tr>
<tr>
<td>Concentrated Organic Manures</td>
<td>62</td>
</tr>
<tr>
<td>Contact Herbicides</td>
<td>152</td>
</tr>
<tr>
<td>Continental Tropical Air Masses</td>
<td>24</td>
</tr>
<tr>
<td>Continuous Cropping</td>
<td>106, 107</td>
</tr>
<tr>
<td>Conveyance and Distribution of Water</td>
<td>94</td>
</tr>
<tr>
<td>Cotton</td>
<td>377</td>
</tr>
<tr>
<td>Adaptation</td>
<td>379</td>
</tr>
<tr>
<td>Area and Production</td>
<td>379</td>
</tr>
<tr>
<td>Botanical Description</td>
<td>380</td>
</tr>
<tr>
<td>Cropping Systems</td>
<td>381</td>
</tr>
<tr>
<td>Cultivation</td>
<td>381</td>
</tr>
<tr>
<td>Diseases</td>
<td>386</td>
</tr>
<tr>
<td>Fertilization</td>
<td>382</td>
</tr>
<tr>
<td>Harvesting</td>
<td>385</td>
</tr>
<tr>
<td>Insect Pests</td>
<td>386</td>
</tr>
<tr>
<td>Land Preparation</td>
<td>381</td>
</tr>
<tr>
<td>New World Cotton</td>
<td>378</td>
</tr>
<tr>
<td>Old World Cotton</td>
<td>377</td>
</tr>
<tr>
<td>Origin and Distribution</td>
<td>377</td>
</tr>
<tr>
<td>Plant Protection</td>
<td>386</td>
</tr>
<tr>
<td>Processing</td>
<td>385</td>
</tr>
<tr>
<td>Rotation</td>
<td>109</td>
</tr>
<tr>
<td>Sowing</td>
<td>381</td>
</tr>
<tr>
<td>Utilization</td>
<td>379</td>
</tr>
<tr>
<td>Water Use</td>
<td>383</td>
</tr>
<tr>
<td>Weed Control</td>
<td>384</td>
</tr>
<tr>
<td>Yields</td>
<td>385</td>
</tr>
<tr>
<td>Cover Crops</td>
<td>57</td>
</tr>
<tr>
<td>Cowpeas</td>
<td>292</td>
</tr>
<tr>
<td>Adaptation</td>
<td>293</td>
</tr>
<tr>
<td>Area and Production</td>
<td>292</td>
</tr>
<tr>
<td>Black-Eyed Beans</td>
<td>292</td>
</tr>
<tr>
<td>Black-Eyed Peas</td>
<td>292</td>
</tr>
<tr>
<td>Botanical Description</td>
<td>293</td>
</tr>
<tr>
<td>China Peas</td>
<td>292</td>
</tr>
<tr>
<td>Crop Protection</td>
<td>297</td>
</tr>
<tr>
<td>Cropping Systems</td>
<td>294</td>
</tr>
<tr>
<td>Cultivation</td>
<td>294</td>
</tr>
<tr>
<td>Diseases</td>
<td>297</td>
</tr>
<tr>
<td>Fertilization</td>
<td>296</td>
</tr>
<tr>
<td>Harvesting and Threshing</td>
<td>297</td>
</tr>
<tr>
<td>Insect Pests</td>
<td>298</td>
</tr>
<tr>
<td>Land Preparation</td>
<td>295</td>
</tr>
<tr>
<td>Marble Peas</td>
<td>292</td>
</tr>
<tr>
<td>Origin and Distribution</td>
<td>292</td>
</tr>
<tr>
<td>Sowing</td>
<td>295</td>
</tr>
<tr>
<td>Storage</td>
<td>297</td>
</tr>
<tr>
<td>Utilization</td>
<td>292</td>
</tr>
<tr>
<td>Water Use</td>
<td>296</td>
</tr>
<tr>
<td>Weed Control</td>
<td>297</td>
</tr>
<tr>
<td>Yields</td>
<td>297</td>
</tr>
<tr>
<td>Crop Establishment Practices</td>
<td>119</td>
</tr>
<tr>
<td>Crop Response to Water</td>
<td>86</td>
</tr>
<tr>
<td>Moisture Stress</td>
<td>16</td>
</tr>
<tr>
<td>Residues</td>
<td>146</td>
</tr>
<tr>
<td>Rotation</td>
<td>56, 108, 151</td>
</tr>
<tr>
<td>Site Selection</td>
<td>119</td>
</tr>
<tr>
<td>Statistics for the World and Africa</td>
<td>10</td>
</tr>
<tr>
<td>Statistics of the World</td>
<td>13</td>
</tr>
<tr>
<td>Cropping</td>
<td>129</td>
</tr>
<tr>
<td>Cycle</td>
<td>140</td>
</tr>
<tr>
<td>on Steep Slopes</td>
<td>53</td>
</tr>
<tr>
<td>Pattern for High Water-Use</td>
<td>94</td>
</tr>
<tr>
<td>Systems</td>
<td>103, 116</td>
</tr>
<tr>
<td>Day Length</td>
<td>140</td>
</tr>
<tr>
<td>Decomposition</td>
<td>41, 42, 43</td>
</tr>
<tr>
<td>Decomposition of Organic Matter</td>
<td>40, 42</td>
</tr>
<tr>
<td>Denitrification</td>
<td>44</td>
</tr>
<tr>
<td>Development of Water Resources</td>
<td>94</td>
</tr>
<tr>
<td>Disease Organisms</td>
<td>147</td>
</tr>
<tr>
<td>Disease Organisms and Pests</td>
<td>146</td>
</tr>
<tr>
<td>Dispersal of Domesticated Crops</td>
<td>6</td>
</tr>
<tr>
<td>Dominant Alleles</td>
<td>3</td>
</tr>
<tr>
<td>Dormant Seeds</td>
<td>135, 142</td>
</tr>
<tr>
<td>Drainage</td>
<td>99</td>
</tr>
<tr>
<td>Shifting Cultivation</td>
<td>104</td>
</tr>
<tr>
<td>Drip Irrigation</td>
<td>93</td>
</tr>
<tr>
<td>Droughts</td>
<td>16</td>
</tr>
<tr>
<td>Drug Crops</td>
<td>9, 415</td>
</tr>
<tr>
<td>Dry Tropical Climates</td>
<td>26</td>
</tr>
<tr>
<td>Economic Classification</td>
<td>8</td>
</tr>
<tr>
<td>Economic Exploitation</td>
<td>121</td>
</tr>
<tr>
<td>Economic Status of the Developing Nations</td>
<td>13</td>
</tr>
<tr>
<td>Electrical Resistance Block</td>
<td>79, 82</td>
</tr>
<tr>
<td>Elements of Climate</td>
<td>15</td>
</tr>
<tr>
<td>Emergence and Seedling Vigour</td>
<td>141</td>
</tr>
<tr>
<td>Entisols</td>
<td>10</td>
</tr>
<tr>
<td>Equator</td>
<td>24, 25</td>
</tr>
<tr>
<td>Equatorial Climatic Zone</td>
<td>23</td>
</tr>
<tr>
<td>Erosion</td>
<td>53</td>
</tr>
<tr>
<td>Caused by Water</td>
<td>48</td>
</tr>
<tr>
<td>Caused by Wind</td>
<td>53</td>
</tr>
<tr>
<td>Control</td>
<td>54</td>
</tr>
</tbody>
</table>
Erosivity  59
Essential Nutrients  59
Essential Nutrition Elements  59
Ethiopian or African Centre  5
Evapotranspiration  17, 20, 21, 22, 83
  Consumptive use  83
  Potential Evapotranspiration  84
  Requirement  84
Fallowing  106, 107
FAO Production Yearbook for 1989  234, 251, 267, 268, 277
FAO/UNESCO (1971-78)  30
Soil Map of the World  30
Farnayr Munure  60, 61
Fe and Al Oxides  52
Foreign Seed Matter  134
Fertilizer Application  73
  Band Placement  74
  Broadcast at Planting  74
  Direct  75
  Foliar  75
  Hill Placement  75
  Into the Soil  75
  Liquid  74
  Plough-Sole Placement  74
  Side Dressing  74
  Solid  74
  Starter Solution  75
  Through Irrigation Water  75
  Top Dressing  74
Fertilizers Supplied
  Micronutrients  69
  Fertilizers Supplied Secondary
  Nutrients  68
Fibre Crops  9, 375
  Synthetic Fibres  375
  Vegetable Fibres  375
  Wool  375
Field and Garden Peas  311
  Adaptation  312
  Area and Production  311
  Botanical Description  312
  Crop Protection  314
  Cropping Systems  312
  Cultivation  312
  Fertilization  313
  Harvesting and Threshing  314
  Insect Pests  314
  Land Preparation  313
  Origin and Distribution  311
  Sowing  313
  Storage  314
  Utilization  311
  Water Use  313
  Weed Control  313
  Yields  314
Field Drainage Systems  100
  Field Oil-Seed Crops  322
  Final Percentage Emergence  142
  Fire as a Weed Control Device  149
  Flume Thowers  150
  Flaming  150
  Flooding  86, 150
  Floral Initiation  19
  Flowering  87
  Forage Crops  9
  Forest Clearing  34
  Forestry  103
  Functions of Soil Micro-
    Organisms  41
  Fungi  42
  Furrow  90
Gene Centres  3
Geographical Distribution  2
Germination of the Seed  136
  Failure  133, 134
Germination Tests  135
Government-Sponsored Farms  116
Grades of Fertilizer Mixtures  71
Grading and Terracing  129
Grain Formation  87
Grain Legumes  9
  Cereals Excellent Source of
    Energy (Starch)  289
  Groundnuts  290
  Nutritional Importance  289
  Nutritional Values  291
  Protein  289
  Soybeans  290
Green Manures  61
Groundnuts  324
  Adaptation  325
  Area and Production  324
  Botanical Description  326
  Crop Protection  333
  Cropping Systems  328
  Cultivation  328
  Diseases  333
  Fertilization  330
  Harvesting  332
  Insect Pests  335
  Land Preparation  329
  Nematodes  334
  Origin and Distribution  324
  Seed Treatment  329
  Storage  333
  Types of Groundnuts  327
  Utilization  324
  Water Use  330
  Weed Control  311
  Yields  333
  Growth Inhibitors  144
  Gully Erosion  49, 50
<table>
<thead>
<tr>
<th>Heading/Earing 87</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hemp 391</td>
</tr>
<tr>
<td>Adaptation 391</td>
</tr>
<tr>
<td>Area and Production 391</td>
</tr>
<tr>
<td>Botanical Description 392</td>
</tr>
<tr>
<td>Cultivation 392</td>
</tr>
<tr>
<td>Fertilization 392</td>
</tr>
<tr>
<td>Harvesting 392</td>
</tr>
<tr>
<td>Origin and Distribution 391</td>
</tr>
<tr>
<td>Hemp Processing 392</td>
</tr>
<tr>
<td>Utilization 391</td>
</tr>
<tr>
<td>Weed Control 392</td>
</tr>
<tr>
<td>Yields 393</td>
</tr>
<tr>
<td>Herbicide Action 152</td>
</tr>
<tr>
<td>Application 151</td>
</tr>
<tr>
<td>Chemical Nature 153</td>
</tr>
<tr>
<td>Non-Selective 152</td>
</tr>
<tr>
<td>Post-Emergence 151</td>
</tr>
<tr>
<td>Pre-Emergence 151</td>
</tr>
<tr>
<td>Pre-Planting 151</td>
</tr>
<tr>
<td>Residues 153</td>
</tr>
<tr>
<td>Selective 151</td>
</tr>
<tr>
<td>Selectivity 152</td>
</tr>
<tr>
<td>Heterotrophic Bacteria 42</td>
</tr>
<tr>
<td>High Intensity Storms 17</td>
</tr>
<tr>
<td>History of Crop Dispersal 6</td>
</tr>
<tr>
<td>History of Legume Culture 290</td>
</tr>
<tr>
<td>Histosols 30</td>
</tr>
<tr>
<td>Hot, Short Dry Spell Zone 22</td>
</tr>
<tr>
<td>Hot, Wet Zone 22</td>
</tr>
<tr>
<td>Humidity 20</td>
</tr>
<tr>
<td>Fungus Diseases of Crops 21</td>
</tr>
<tr>
<td>Relative Humidity 20, 21</td>
</tr>
<tr>
<td>Water Vapour in the Air 20</td>
</tr>
<tr>
<td>Hydrogen Ions 38</td>
</tr>
<tr>
<td>Inceptisols 30</td>
</tr>
<tr>
<td>Incidence of Diseases and Pests 140</td>
</tr>
<tr>
<td>Incipient Agriculture 1</td>
</tr>
<tr>
<td>Indigenous Crops of Africa 7</td>
</tr>
<tr>
<td>Cereals 7</td>
</tr>
<tr>
<td>Coffee 7</td>
</tr>
<tr>
<td>Fibre Crops 7</td>
</tr>
<tr>
<td>Grain Legumes 7</td>
</tr>
<tr>
<td>Kolanut 7</td>
</tr>
<tr>
<td>Oil-Seeds 7</td>
</tr>
<tr>
<td>Watermelon 7</td>
</tr>
<tr>
<td>Yams 7</td>
</tr>
<tr>
<td>Indigenous Systems of Farming 47</td>
</tr>
<tr>
<td>Inorganic Clay Colloids 37</td>
</tr>
<tr>
<td>Inter-Tropical Convergence Zone (ITCZ) 24</td>
</tr>
<tr>
<td>Intercropping 111, 127</td>
</tr>
<tr>
<td>International Centre for Wheat and Maize Improvement (CIMMYT) 13</td>
</tr>
<tr>
<td>International Rice Research Institute (IRRI) 13</td>
</tr>
</tbody>
</table>

<p>| International Society of Soil Science 32 |
| Internode 138 |
| Intertropical Front or Equatorial Trough 24 |
| Introduced Crops Grown in Africa 8 |
| Beverage Crops 8 |
| Cereals 8 |
| Drug Crop 8 |
| Fibre Crops 8 |
| Grain Legumes 8 |
| Latex Crops 8 |
| Oil-Seeds 8 |
| Roots and Tubers 8 |
| Sugar Crop 8 |
| Iron and Aluminium Hydrous Oxide Clays 37 |
| Irrigation 77 |
| Development Programme 93 |
| Methods 87 |
| Irrigation Requirements 84, 95, 98 |
| Barley 98 |
| Building 96 |
| Cotton 98 |
| Crown Roots 96 |
| Efficiency 85 |
| Frequency 85 |
| Grain Legumes 98 |
| Gross 85 |
| Jointing 96 |
| Land Submergence 96 |
| Maize 97 |
| Millet 97 |
| Nett 85 |
| Oil-Seed Crops 98 |
| Rice 95 |
| Sorghum 97 |
| Sugarcane 99 |
| Tilling 96 |
| Timing 95 |
| Wheat 96 |
| Irrigation Scheduling 86 |
| Jointing 87 |
| Kenaf and Roselle 387 |
| Adaptation 387 |
| Botanical Description 388 |
| Crop Protection 390 |
| Cultivation 388 |
| Diseases 390 |
| Fertilization 388 |
| Harvesting 389 |
| Insect Pests 390 |
| Land Preparation 388 |
| Origin and Distribution 387 |
| Processing 389 |
| Seed Production 389 |
| Sowing 388 |</p>
<table>
<thead>
<tr>
<th>Index</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil Cakes 62</td>
<td>Transplanting 459</td>
</tr>
<tr>
<td>Crops 9</td>
<td>Utilization 456</td>
</tr>
<tr>
<td>Oil Palm 363, 372</td>
<td>Yields 461</td>
</tr>
<tr>
<td>Adaptation 364</td>
<td>Parasitic Fungi 42</td>
</tr>
<tr>
<td>Area and Production 363</td>
<td>Parasitic Weeds 146</td>
</tr>
<tr>
<td>Botanical Description 365</td>
<td>Patch Intercropping 111</td>
</tr>
<tr>
<td>Crop Protection 372</td>
<td>Pathogens 110</td>
</tr>
<tr>
<td>Cultivation 368</td>
<td>Pathogens in the Seed 142</td>
</tr>
<tr>
<td>Diseases 372</td>
<td>Perennial Crops 26, 112</td>
</tr>
<tr>
<td>Drupe (Fruit) 368</td>
<td>Perennial Weeds 144, 152</td>
</tr>
<tr>
<td>Fertilization 370</td>
<td>Pest and Disease Control 114</td>
</tr>
<tr>
<td>Harvest 371</td>
<td>Pesticides 134</td>
</tr>
<tr>
<td>Insect Pests 373</td>
<td>Phosphatic Fertilizers 65, 67</td>
</tr>
<tr>
<td>Intercropping 370</td>
<td>Phosphorus Retention in Soils 66</td>
</tr>
<tr>
<td>Nursery 369</td>
<td>Phosphorus Saturation of the Soil 66</td>
</tr>
<tr>
<td>Origin and Distribution 363</td>
<td>Photoperiod 140</td>
</tr>
<tr>
<td>Other Pests 373</td>
<td>Photoperiodism 19</td>
</tr>
<tr>
<td>Pre-Nursery 368</td>
<td>Photosynthesis 141</td>
</tr>
<tr>
<td>Processing 371</td>
<td>Photosynthesizing Organs 133</td>
</tr>
<tr>
<td>Propagation 368</td>
<td>Pigeon Peas 305</td>
</tr>
<tr>
<td>Transplanting in the Field 369</td>
<td>Adaptation 306</td>
</tr>
<tr>
<td>Utilization 364</td>
<td>Area and Production 305</td>
</tr>
<tr>
<td>Weed Control 370</td>
<td>Botanical Description 306</td>
</tr>
<tr>
<td>Yields 372</td>
<td>Crop Protection 310</td>
</tr>
<tr>
<td>Oil-Seed Crops 321</td>
<td>Cropping Systems 306</td>
</tr>
<tr>
<td>By-Products 322</td>
<td>Cultivation 306</td>
</tr>
<tr>
<td>Content of Various Crops 323</td>
<td>Diseases 310</td>
</tr>
<tr>
<td>Essential Volatile Oils 321</td>
<td>Fertilization 308</td>
</tr>
<tr>
<td>Field Crops 322</td>
<td>Harvesting 309</td>
</tr>
<tr>
<td>Non-Volatile Oils 321</td>
<td>Insect Pests 310</td>
</tr>
<tr>
<td>Oils from Oil-Seed 321</td>
<td>Land Preparation 307</td>
</tr>
<tr>
<td>Trees 322</td>
<td>Origin and Distribution 305</td>
</tr>
<tr>
<td>Okro Varieties 140</td>
<td>Sowing 307</td>
</tr>
<tr>
<td>Organic Colloids (Humus) 38</td>
<td>Storage 310</td>
</tr>
<tr>
<td>Organic Matter 40</td>
<td>Utilization 305</td>
</tr>
<tr>
<td>Organization of Economic</td>
<td>Weed Control 309</td>
</tr>
<tr>
<td>Cooperation and</td>
<td>Yields 309</td>
</tr>
<tr>
<td>Development (OECD) 12</td>
<td>Plant Nutrients 40</td>
</tr>
<tr>
<td>Origin of Cultivated Crops 3</td>
<td>Plant Nutrition 59</td>
</tr>
<tr>
<td>Over-Seeding 136</td>
<td>Plant-Water Relationships 83</td>
</tr>
<tr>
<td>Overhead Irrigation 91</td>
<td>Poor Emergence 142</td>
</tr>
<tr>
<td>Oxisols 31</td>
<td>Poor Germination 142</td>
</tr>
<tr>
<td>Oxygen Deficiency 36</td>
<td>Position of Agriculture in Africa 12</td>
</tr>
<tr>
<td>Para Rubber 456</td>
<td>Position of Seed with Respect to Land</td>
</tr>
<tr>
<td>Adaptation 457</td>
<td>Preparation 138</td>
</tr>
<tr>
<td>Area and Production 456</td>
<td>Potassic Fertilizers 67, 68</td>
</tr>
<tr>
<td>Botanical Description 457</td>
<td>Potassium Retention in Soils 67</td>
</tr>
<tr>
<td>Crop Protection 461</td>
<td>Availability to Plants 39</td>
</tr>
<tr>
<td>Cultivation 458</td>
<td>Potassium Fixation 68</td>
</tr>
<tr>
<td>Diseases 461</td>
<td>Predicting Germination 134</td>
</tr>
<tr>
<td>Fertilization 459</td>
<td>Presence of Perennating Organs 144</td>
</tr>
<tr>
<td>Maintenance 459</td>
<td>Pressure Membrane 79</td>
</tr>
<tr>
<td>Origin and Distribution 456</td>
<td>Pressure Plate Technique 79</td>
</tr>
<tr>
<td>Pests 461</td>
<td>Prostrate Crop 146</td>
</tr>
<tr>
<td>Processing 460</td>
<td>Protozoa 41</td>
</tr>
<tr>
<td>Propagation 458</td>
<td>Protracted Storage of the Seed 142</td>
</tr>
<tr>
<td>Tapping 459</td>
<td></td>
</tr>
</tbody>
</table>