Agroforestry Species: A Crop Sheets Manual

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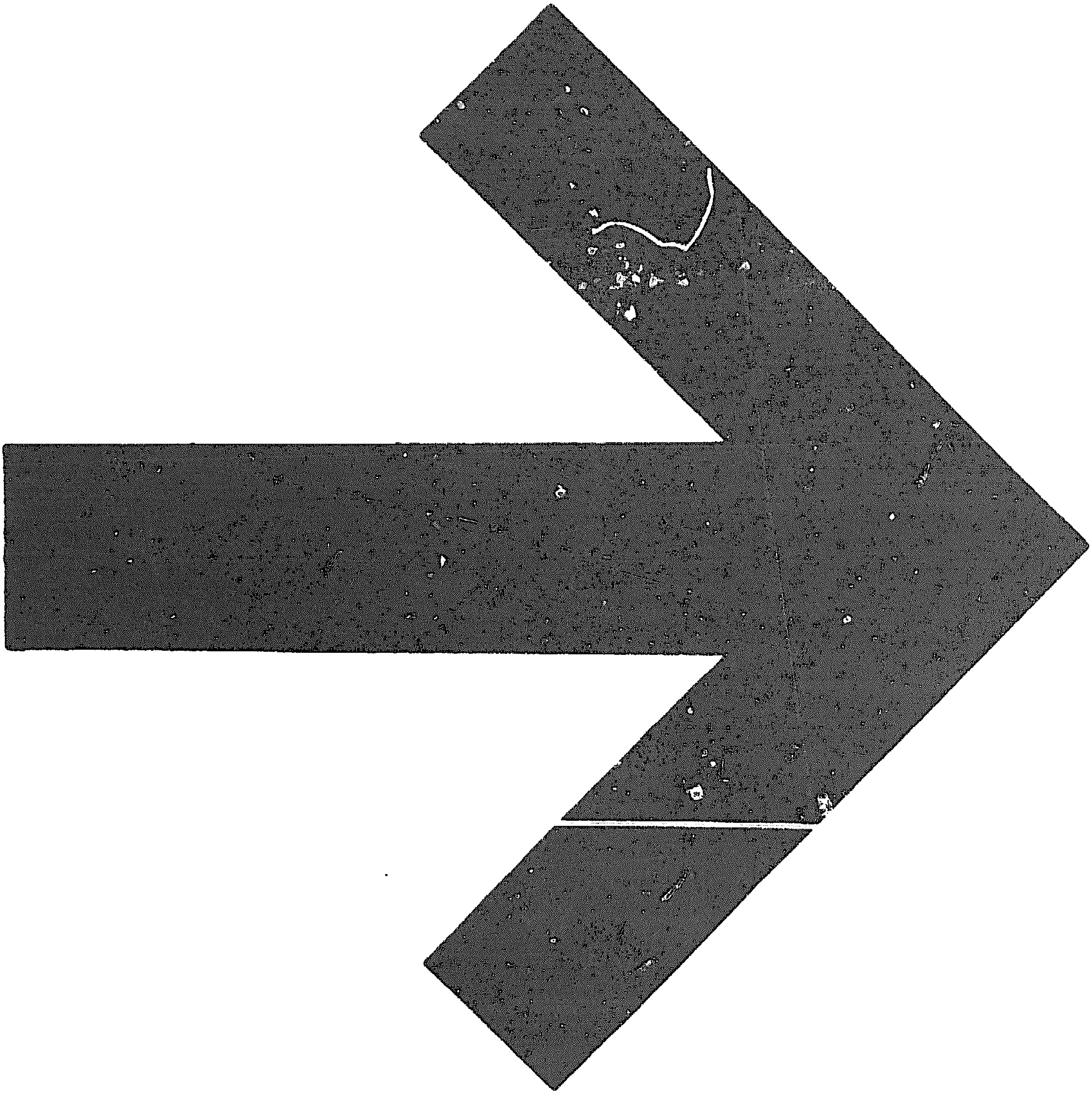

AGROFORESTRY SPECIES

A CROP SHEETS MANUAL

CONTENTS

FOREWORD

The growing of trees and crops intermixed on the same piece of land is an old and indigenous practice followed by farmers in many ecological zones in many countries of the world. Agroforestry - the elegant term for the practice - is being increasingly recognized as a land-use/food production system which has a high potential for stabilizing food production, for providing many "tree" products - both traditional, e.g. charcoal, and new - while at the same time, exerting a stabilizing influence on the environment.

ICRAF realized that information on plant materials which could be used in agroforestry systems was scattered in many publications and papers, some of which were scarce or out of print. To fill this gap, Dr. Nair has undertaken to bring together a set of "crop" sheets describing some plant materials which can be used in agroforestry.

This is neither an exhaustive treatment of the species described nor is it a definite list of species to be used. Rather this is a selected list of "crops" and has not treated the subject of tree species although some tree crops are included, for example, cacao, cashew and rubber to name but three. We expect this publication to be the first of a series; a future one will deal with tree species and additional crops that can be used in agroforestry - as more information is obtained, the usefulness of the publications will be enhanced.

One further component of agroforestry systems, namely the animal, will also be dealt with in a future publication.

We invite your comments on the usefulness of the crop sheets, and your suggestions for material to be treated in future publications. We trust that you, the agroforestry worker, whether you were trained as a forester or an agriculturist, will find it of benefit to you in your work.

Howard A. Steppler
Director-General Interim
ICRAF

Nairobi
October, 1980

PREFACE

With the increasing realization of the importance of agroforestry as a sustainable land-use system, there is a growing enthusiasm among foresters to learn about agricultural species and their cultivation practices, and similarly among agriculturalists to know about forestry species and their management. In view of this, we at ICRAF deemed it advisable to prepare "crop sheets" on species suited to agroforestry, so as to collate information available in a variety of books and other reference materials, and to prepare short, concise accounts on such species from the point of view of their suitability for agroforestry.

The choice of species to be included in such a manual has been extremely difficult because there is no distinct group of agroforestry species, nor has a sizeable body of knowledge been built up on the preformance of species in agroforestry-like situations. Most of the important agricultural crops and their management have hitherto been developed and promoted to suit sole cropping conditions, and they give their best yields under optimum agronomic and environmental conditions, including an uninhibited supply of sunlight which cannot be obtained in agroforestry situations. At the same time the very need for agroforestry implies that the important agricultural species - especially food crops like cereals and pulses - need to be included, despite the fact that there will be sub-optimal conditions for their growth. Under the circumstances, a few species each have been selected arbitrarily from the different groups of economic plants, based on their importance in peasant farming and dietary habits, adaptability to low input systems, and supposed amenability to agroforestry; the list is by no means exhaustive. Since agroforestry is intended mainly for the tropics, only species suited to tropical conditions have been included.

The manual is arranged in three parts. Part I, which deals with the general principles and concepts of agroforestry in the context of tropical land-use patterns, was felt necessary because those principles have not previously been adequately expounded, owing to the nascent stage of the discipline.

PREFACE

Part II contains the crop sheets of 40 selected species that are widely cultivated and whose production potentials have been relatively well exploited. Considering the diversity in the growth requirements and growing habits of the different cultivars and agronomic varieties of each of the species and the volume of research information available for some of them (though mostly for monoculture conditions), only a very general treatment is attempted. The information is grouped under a uniform format consisting of scientific and common (English, French and Spanish) names, uses and economic importance, origin and distribution, plant characteristics, physiology and composition, agronomy, yield, pests and diseases and a brief account on the supposed agroforestry potential of each species. The names of major research institutions carrying out research on the crops in the developing countries, together with a small selected bibliography has also been included. In addition, a list of general references is given to indicate sources of detailed information. Besides these relatively important species, there are some underexploited and localized species with agroforestry potential: short notes on 50 such species are included as Part III. The general references give additional information on these species also.

I hope that the manual will serve as a ready reckoner for the worker - especially the forester - in the field. It is expected to be useful in the choice of agricultural species for areas whose agricultural history is unknown or little-known, and as a glossary and aid in the preparation of farming system projects and crop calendars for specific regions. Along with the subsequent volumes of crop sheets on additional tree and fodder species which ICRAF intends to publish in due course, the manual could also be useful in agroforestry education and training.

The reference materials and text books that have been listed in the general references, notably Acland (1971), ICAR (1966), Kay (1973; 1979), National Academy of Sciences (1975); 1979) and Purseglove (1974), have been liberally consulted in preparing the crop sheets, especially for describing plant characteristics. The sources of the tables and figures used in the text have been indicated and copyright permission obtained wherever necessary. Due credit has also been given to the photographs obtained from external sources. I am extremely thankful to all concerned for their cooperation in this matter.

The proposal to compile and publish the crop sheet was accepted and many useful directives were given by ICRAF's Board of Trustees and its programme committee. Dr. K.F.S. King, the first director-general of ICRAF, provided the necessary driving force for its expeditious compilation and publication by his constant encouragement and support. Dr. Howard A. Steppler, ICRAF's interim director-general, also lent his full support and cooperation to the effort and he wrote the foreword. My scientist colleagues in ICRAF contributed to the endeavour by many suggestions and active participation in the discussions. Mr. David Spurgeon, who has been ICRAF's Senior Science Writer, helped me splendidly in technical editing and publication aspects. Much of the draft typing was done by Ms Charity Kanyeki, while the camera-ready typescript was prepared by Ms Winifred Kuria. I am grateful to all of them for their support and cooperation.

Nairobi
October, 1980

P.K.R. Nair

PART I

GENERAL PRINCIPLES OF AGROFORESTRY

THE TROPICAL ENVIRONMENT IN RELATION TO AGROFORESTRY

THE TROPICS

In geographical terms, "that part of the world located between 23.5 degrees north and south of the equator" constitutes the tropics. This land mass accounts for 38 per cent of the earth's surface and 45 per cent of the world's population (about 1.8 billion people in 1975). Since most of the developing countries are in the tropics and few regions in the tropics (e.g. tropical Australia, Hawaii) are considered "developed" areas, "the tropics" is usually used as a synonym for "the developing regions", although the reverse is not true. Since the climatic changes with respect to latitude are gradual, a quantitative definition of the tropics based on latitude loses its value at the geographical tropical boundaries. Therefore, countries like India, Bangla Desh, Mexico and Brazil, which transcend geographical tropical boundaries, are still considered to be tropical countries in common parlance (see Fig. 1).

CLIMATIC FEATURES

Temperature and rainfall are by far the two most important parameters determining the climatic features of a region. In general, the mean monthly variation of temperature between the warmer and colder seasons in a tropical area is 5^{o}C or less, and this is true even in tropical highlands, where the overall temperatures are low. For every 100 m increase in elevation in the tropics, there is a decline of 0.6^{o}C in the mean annual temperature. Thus, if the mean annual temperature at sea level is 26^{o}C, it will be 20^{o}C at 1000 m and 14^{o}C at 2000 m. These temperature patterns, including the relative constancy of temperature, affect the growth of certain crops in tropical highlands, where neither lowland tropical species nor temperate species find their optimum growth requirements.

In terms of annual rainfall, the tropics present a most diverse picture: it varies from 0 to 10,000 mm. Thus, both deficits and excesses of rainfall create problems for plant production

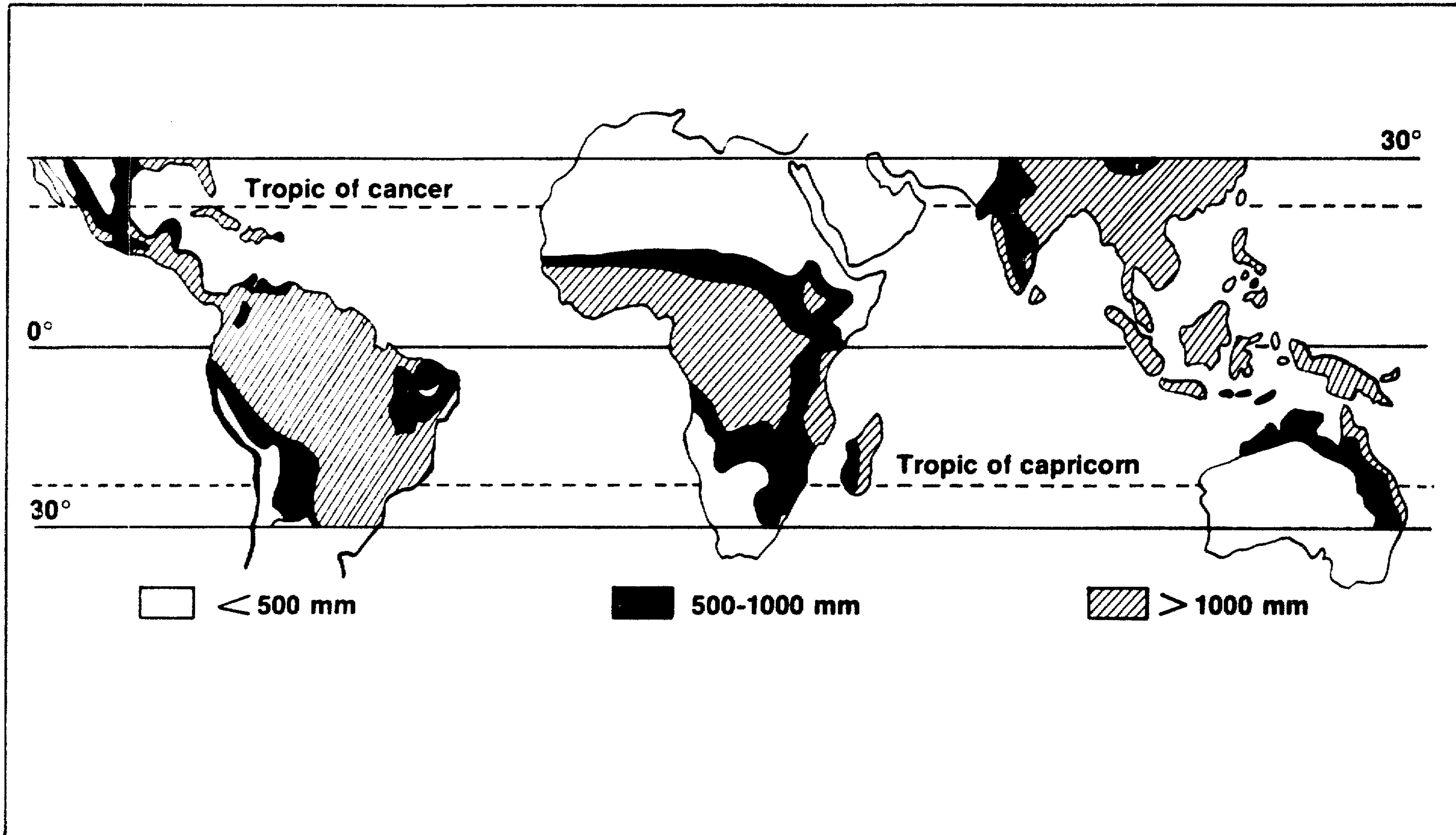

Fig. 1. Annual rainfall regimes of tropical and subtropical regions of the world (Isbell, 1978)

in the tropics. The annual rainfall regimes of tropical and subtropical regions of the world are given in Fig. 1. However, the distribution rather than the total amount of rainfall is more important for plant growth. When the average precipitation at a place during a period is more than the average evapotranspiration, that period is termed humid, and depending upon the number of humid months, some climatic descriptions have been attempted (see later). As a corollary, different climatic regions have been formed based on the length of the dry season, a dry month being one in which rainfall is less than 100 mm. Thus, four major climatic regions have been identified in the tropics and they are given in Table 1.

Depending upon the rainfall distribution pattern, there is also seasonal variation in received solar radiation in the tropics. In general, the tropics receive an average solar radiation of 400 langleys*/day (as compared with an average of 200 langleys/day in the temperate areas), and there is little seasonality in solar radiation in areas with even rainfall distribution. On the other hand, in areas with distinct rainy and dry seasons, there is considerable seasonality. For example, at Los Baños, in the Philippines, the average solar radiation in January is 295 langleys/day whereas in May it is 439 langleys/day. These differences influence plant growth considerably. De Wit (1965) has estimated the potential crop yields in different latitudinal belts based on solar radiation and length of growing season. Calculations from his data indicate the very high production potential per hectare per year in the tropics, where the "photosynthetic factory" can be kept operative throughout the year, unlike in the temperate regions. Therefore, land-use systems in the tropics should aim at maximizing total productivity per unit area rather than that of a particular seasonal crop in a year.

CLIMATE DIAGRAMS

In order to consider climate from an ecological point of view, Walter (1973) has proposed the climate diagram *(Klimadiagramm)*, which gives information concerning the mean temperature and

* *1 langley = 1 gram-calorie/cm^2*

Table 1 Distribution of major climatic regions in the tropics, based on the Landsberg-Troll classification (million ha)

Climate	Humid Months	Predominant Vegetation	Tropical America	Tropical Africa	Tropical Asia	Total	Percent
Rainy	9.5-12	Rain-forest and forest	646	197	348	1191	24
Seasonal	4.5-9.5	Savanna or deciduous forest	802	1144	484	2430	49
Dry	2-4.5	Thorny shrubs and trees	84	486	201	771	16
Desert	0-2	Desert and semi-desert scrub	25	304	229	558	11
Total			1557	2131	1262	4950	100

Source: Sanchez (1976) as adapted from the U.S. President's Science Advisory Committee (1967).

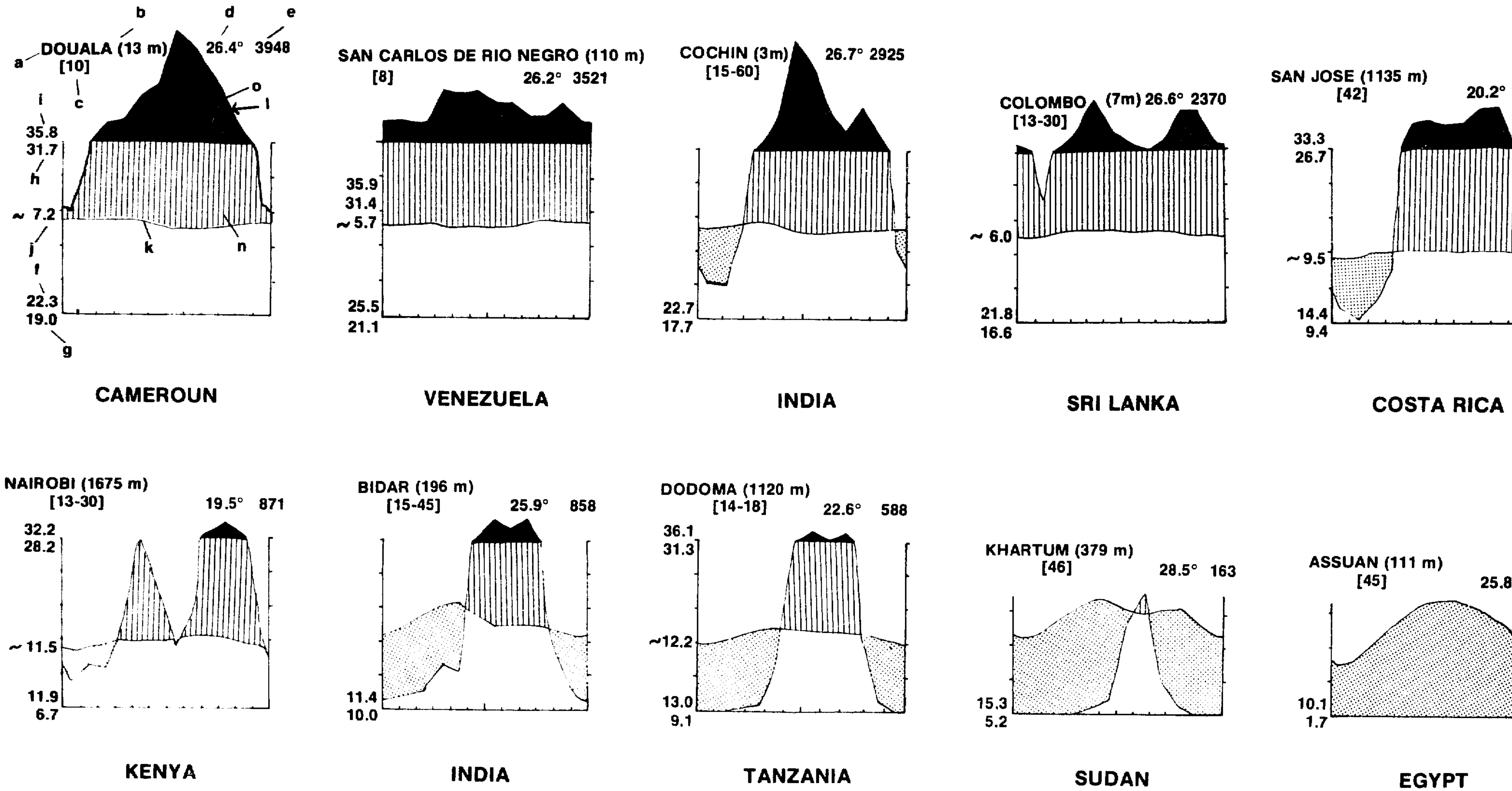

Fig. 2a. Some climate diagrams from different parts of the tropics (from Walter, 1973).

Key to the climate diagrams. Abscissa: Months (N. Hemisphere January-December, S. Hemisphere July-June); Ordinate: one division = 10°C or 20 mm rain. a = station, b = height above sea level, c = duration of observations in years (of two figures the first indicates temperature, the second precipitation), d = mean annual temperature in °C, e = mean annual precipitation in mm, f = mean daily minimum of the coldest month, g = lowest temperature recorded, h = mean daily maximum of the warmest month, i = highest temperature recorded, j = mean daily temperature variations, k = curve of mean monthly temperature, l = curve of mean monthly precipitation, m = relative period of drought (dotted), n = relative humid season (vertical shading), o = mean monthly rain >100 mm (black scale reduced to 1/10). Some values are missing, where no data are available for the stations concerned (h-j are only given for dirunal types of climate).

precipitation at a particular locality over the course of the year. The diagrams also show the occurrence, length and intensity of relatively humid and arid seasons. Some climate diagrams from different parts of the tropics are given in Fig. 2a.

The abscissa on a climate diagram shows the calendar months from January to December for the Northern Hemisphere, and from July to June for the Southern Hemisphere, so that the warm season is always in the middle of the diagram. The ordinate gives mean monthly temperature and precipitation at the scale ratio of $10^{o}C$ = 20 mm precipitation up to 100 mm, while above 100 mm the intervals are changed to $10^{o}C$ = 100 mm. The smooth curve denotes temperature and the uneven curve is for precipitation. At the scale ratio of $10^{o}C$ = 20 mm, when the precipitation curve undercuts the temperature curve, a drought season is implied, and that is indicated by stippling in the space where the precipitation curve remains below the temperature line. Humid seasons with monthly precipitation in excess of 100 mm are indicated by hatching in that area on the diagram, and the vertical shading corresponds to relative humid seasons. For a more complete description, see Walter (1973) or Walter *et al.* (1975).

These climate diagrams, which can be easily constructed from the basic meteorological data of a locality, are very useful in indicating the duration and severity of the aridity/humidity of the climate of the locality. Based on these climate diagrams, Ellenberg (1979) has prepared the humidity/aridity series of the natural ecosystems and classified them into eight classes; they are reproduced in Fig. 2b.

VEGETATION TYPES

The classification systems of tropical climates employ distinct names for the predominant vegetation types in the different climatic regions of the tropics. The five general categories are savannas and other grassland (43 per cent of the area); broad-leaved evergreen rain-forests (30 per cent); semi-deciduous forests and shrubs (11 per cent); deciduous forests and shrubs (11 per cent); and desert shrubs and grasses (7 per cent). The savannas, which range from pure grass stands to tree savannas

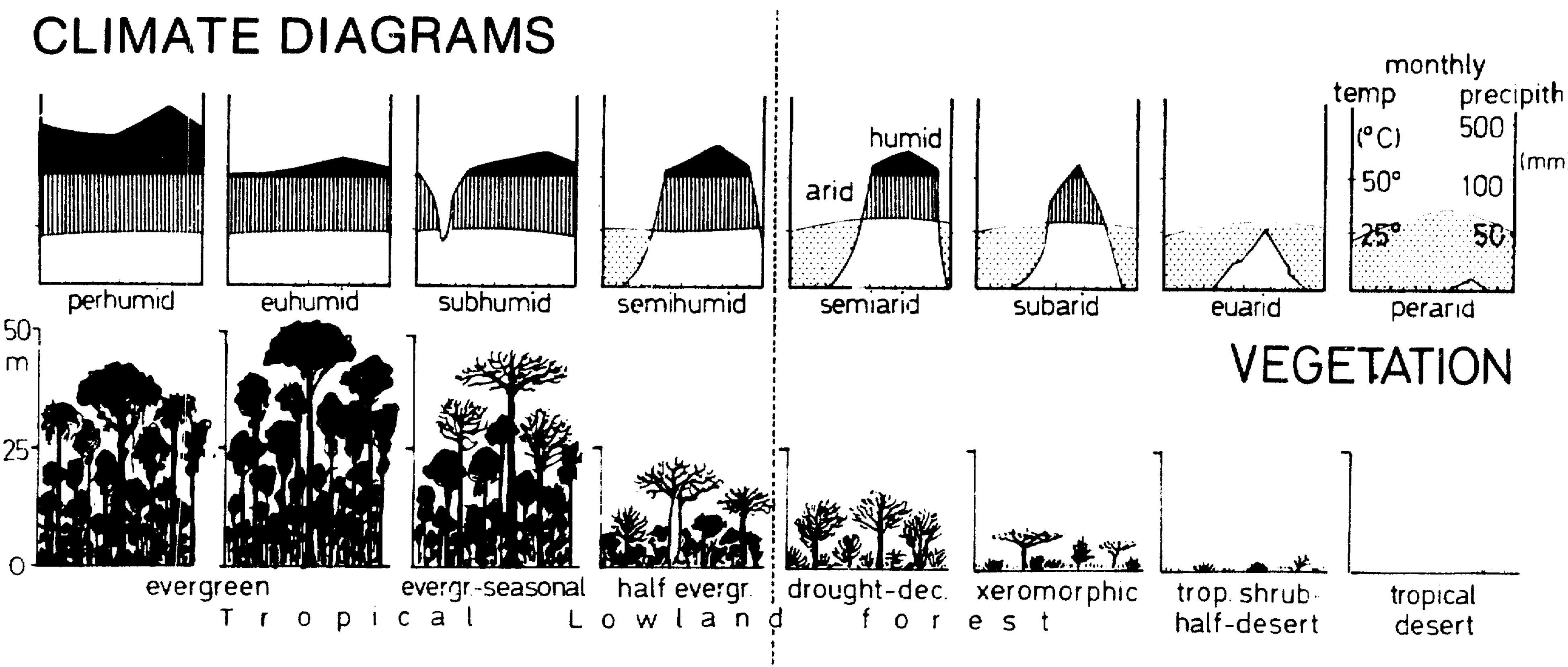

Fig. 2b. Generalized climate diagrams and vegetation profiles of the natural ecosystems in the tropical lowlands of Peru and Ecuador. (Ellenberg, 1979).

with trees and grasses, comprise approximately 28 per cent of the American tropics, 57 per cent of tropical Africa and 34 per cent of tropical Asia and the Pacific (mostly in Australia); for details, see Eyre (1962). Tropical rain-forests characterized by a three-layered canopy and a low proportion of deciduous trees cover about 30 per cent of the tropics; 52 per cent in tropical America; 12 per cent of Africa and 38 per cent of tropical Asia and the Pacific; for details, see Odum (1972). The deciduous and semi-deciduous forests are found in areas with seasonal rainfall and pronounced dry season; they cover about 15 per cent of the tropics, mainly in Asia and Africa, and are also called monsoon forests, miombo forests, or tree steppes. Large tracts of these forests have been converted to savannas by shifting cultivation. Desert and semi-desert scrub, which cover about 7 per cent of the tropics, are found in the extreme arid regions. About 5 per cent of the area of the tropics is devoid of any vegetation cover.

Various estimates are available for the annual dry matter production of various tropical vegetation types. The net primary productivity map of Golley and Leith (1972) gives the following figures of mean annual increases in dry matter production in tons/ha, with the range in brackets: tropical rain-forest 20(10-35); tropical deciduous forests 15(6-35); temperate deciduous forests 10(4-25); tropical savannas 7(2-20); and croplands 6.5(1-40).

TOPOGRAPHY

Approximately 77 per cent of the tropical area forms what is termed "lowlands", with elevations below 900 m. Regions with elevations from 900 to 1800 m constitute about 20 per cent of the area in about half of the Andean highlands of Central and South America, parts of Venezuela and Brazil, the mountain regions of the Caribbean, most of East Africa, the Cameroons, the Deccan Plateau of India and some parts of the southeast Asian mainland. The altitude exceeds 1800 m in about 3 per cent of the tropical area in the Andes of Central and South America, the Ethiopian and Kenyan Highlands, northern Burma, and parts of Indochina and New Guinea.

SOILS*

Soils of the tropics possess a wide range of properties because of the variations in climate, vegetation, parent material, geomorphology and age. Highly weathered, leached soils, previously called "latosols" occupy 51 per cent of the tropics, while sandy, shallow, high-base status, alluvial and moderately leached soils cover the rest. Distribution of the soils in the tropics by climatic regions is given in Table 2a and the extent of major soil orders in the three tropical continents is given in Table 2b. A description on the general fertility status and the management problems of these major soil groups is not attempted here, because usually the fertile soils are used for agriculture or plantations, with the result that the soils available for agroforestry are infertile and poor, either inherently or as a result of defective management.

LAND-USE PATTERNS

A general account of the major vegetation types of the tropics has already been presented, according to which forests account for about 40 per cent of tropical vegetation. Agriculture is the main economic activity, but only about 10 per cent of the total area is used for that. Pastures and meadows account for an additional 20 per cent, but many of these areas are not used to any measurable extent. It is estimated (US President's Science Advisory Committee, 1967) that there are about 1.7 billion ha of potentially arable land in the tropics, of which only about 500 million are currently in use. However, it may be pointed out that the criteria used to denote what is potentially arable or grazing land refer to the average level of agricultural technology in the developed countries. Table 3 indicates the land-use pattern and population in the three tropical continents.

Farming systems in the tropics also vary considerably depending upon the crops grown, population intensity, type of land, resource availability, etc. In general, the farming systems of the tropics can be grouped under five major categories: shifting cultivation, covering 45 per cent of the area; settled subsistence farming

* *adapted from Sanchez (1976)*

Soil Groups (Soil Taxonomy equivalents)	Rainy (9.5-12)*	Seasonal (4.5-9.5)*	Dry and Desert (0-4.5)*	Total	Percent of Tropics
1. Highly weathered, leached soils (Oxisols, Ultisols, Alfisols)	920	1540	51	2511	51
2. Dry sands and shallow soils, (Psamments and lithic groups)	80	272	482	834	17
3. Light-colored, base-rich soils (Aridisols and aridic groups)	0	103	582	685	14
4. Alluvial soils (Aquepts, Fluvents, and others)	146	192	28	366	7
5. Dark-colored, base-rich soils (Vertisols, Mollisols)	24	174	93	291	6
6. Moderately weathered and leached soils (Andepts, Tropepts, and others)	5	122	70	207	5
Total area	1175	2403	1306	4894	100
Percent of tropics	24	49	27	100	

Source: Sanchez (1976) as adapted from the President's Science Advisory Committee (1967).
* Numbers in parentheses refer to number of months with an average rainfall greater than 100 mm.

Table 2b. Approximate extent of major soil suborders in the tropics (million ha)

Order	Suborder	Africa	America	Asia	Total Area	Percent
Oxisols	Orthox	370	380	0	750	15.0
	Ustox	180	170	0	350	7.5
		550	550	0	1100	22.5
Aridisols	All	840	50	10	900	18.4
Alfisols	Ustalfs	525	135	100	760	15.4
	Udalfs	25	15	0	40	0.8
		550	150	100	800	16.2
Ultisols	Aquults	0	40	0	40	1.0
	Ustults	15	35	50	100	2.0
	Udults	85	125	200	410	8.2
		100	200	250	550	11.2
Inceptisols	Aquepts	70	145	70	285	6.0
	Tropepts	0	75	40	115	2.3
		70	220	110	400	8.3
Entisols	Psamments	300	90	0	390	8.0
	Aquents	0	10	0	10	0.2
		300	100	0	400	8.2
Vertisols	Usterts	40	0	60	100	2.0
Mollisols	All	0	50	0	50	1.0
"Mountain areas"		0	350	250	600	12.2
Total		2450	1670	780	4900	100.0

Source: Sanchez (1976)

Table 3 Land use (million ha) and population in the tropical areas

Total	Total Land Area	Cultivated Area[a]	Pastures and Meadows	Forests	Area Cultivated (%)	Population (1969) (millions)	Cultivated Area per Capita (%)
Tropical America	1,683	83	282	914	5	239	0.35
Tropical Africa	2,212	166	652	517	8	275	0.60
Tropical Asia and Pacific[b]	931	256	21	412	27	956	0.26
Tropics	4,826	505	955	1843	10	1470	0.34
World	13,392	1424	3001	4091	11	3647	0.41
Percent Tropics	36	35	32	46	--	40	--

Source: Sanchez (1976)

[a] Annual and perennial crops.

[b] Except Australia.

(17% of the area); nomadic herding (14%); livestock ranching (11%) and plantation systems (4%). Shifting cultivation is practised all over the tropics; in West and Central Africa, the Amazon Basin, Central America and the hillslopes of South-east Asia. In general, the term denotes the system of felling and burning of woody vegetation followed by one to several years of cultivation, and then by a period of forest or bush fallow; the cycle is then repeated. (For a detailed description, see Ruthenberg, 1980). Shifting cultivation occurs usually in the least developed areas, but more than 250 million people depend on it as their means of subsistence. But because they have had to reduce the length of the fallow periods in recent years to accommodate increasing populations, the practice has caused considerable degradation of the soil. On the other extreme, plantation agriculture provides the most sophisticated land-use systems in agriculture in terms of the use of fertilizers, machinery etc., and the soil in this case is usually well-managed.

TROPICAL DEFORESTATION AND AGROFORESTRY

With the increase in the human population, man's activity in the forests and the use of forests and forest products have also increased. This has led to exploitation and over-use or misuse of forests to such an extent that vast areas of once-forested lands have been lost permanently to forestry and other vast areas degraded and damaged beyond recovery, (for example, see Fig. 3). The word deforestation is used to collectively denote all these maladies inflicted on forests by human activity.

The process of tropical deforestation is proceeding at such an alarmingly fast rate that many authorities believe that by the end of the century, much of the biome will have been reduced to improverished remnants - if not destroyed altogether. According to one estimate (FAO, 1977), the forests of the humid tropics had been reduced by the early 1970s to less than 60 per cent of their original area, and the annual loss of these forests was proceeding at a rate of 11 million hectares per year, which is equivalent to as much as 2.0% of the forests in the humid tropics, a rate that would be devastating if allowed to continue for some time. However, as King (1980) has pointed

Fig. 3a. "The Wasted Lands".

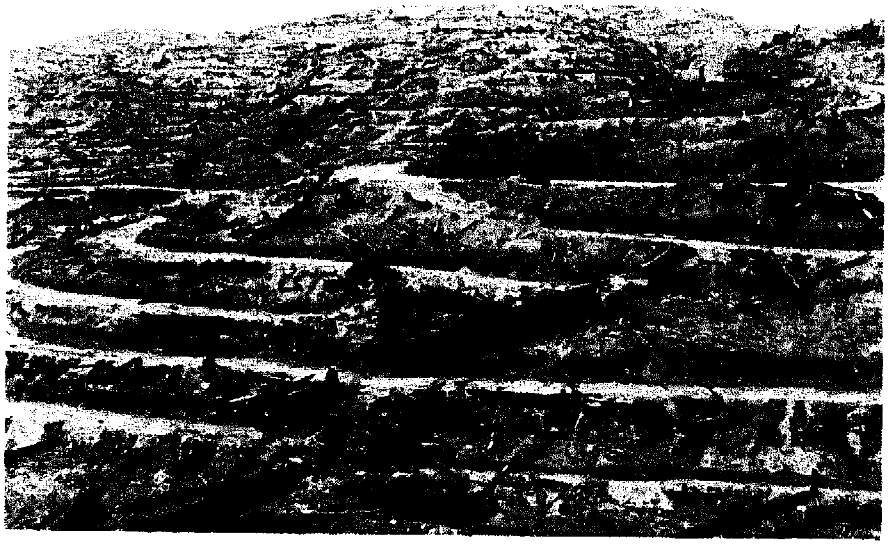

Fig. 3b. Degradation of the forested land when it is converted to agricultural field by conventional practices in Peninsular Malaysia (top) and Amazonia, Brazil (bottom).

out, these data on tropical deforestation should be viewed with caution because of the ambiguity between areas lost to forestry and those going through a process of unmanaged natural regeneration. Therefore, the figures compiled by UNEP (1980) for true deforestation, i.e., the areas with forest cover that are to be replaced by non-forest types of vegetation, are relevant. They are:

(a) in Central and South America, the natural tropical hardwood forests will shrink from 788 million ha in 1975 to 562 million by the year 2000;

(b) in Africa south of the Sahara, the natural moist tropical forest estate will be reduced from 202 million ha in 1975 to 187 million ha in the year 2000; and

(c) in Asia and the Far East, closed natural forests will diminish in area from 291 million ha in 1975 to 243 million ha in the year 2000.

This decline of tropical forests will have many disastrous consequences; important among the recognized ones are the following: the deleterious effect on the biosphere caused by the conversion of the forest biomass to gaseous carbon dioxide; changes in the water status and hydrology of the general area; increased water runoff along the soil surface causing enhanced soil erosion and silt deposition in rivers and reservoirs; decline in the water table and drying of the land, making the area more prone to drought; loss of a potentially renewable source of foreign exchange to the tropical countries; and the extinction of the many uniquely valuable yet unidentified species of plants and animals that will be of importance to agriculture, forestry, medicine and industry.

The major reasons for clearing the forests are three: to make land useful for agriculture, to provide firewood, and to yield wood for lumber. On a global scale the last reason is not as important as the first two. By far the largest loss of tropical forests is due to the transfer of forest land to food production, principally by defective shifting cultivation, and by creation of new settlements in forest areas. Due to demographic factors such as increased population and migration, and in some instances due to governmental policies leading to a reduction of the land available for shifting cultivation, the area that is available per family has been considerably reduced. That results in destruction of more and more forests and shortening of the fallow periods between shifting cultivation cycles, so that the soils are not allowed the time to be rehabilitated.

The demand for firewood and poles is also inflicting serious losses to the tropical forests. According to King (1980), about 90 per cent of the wood that was harvested in Africa, 82 per cent of that in Central and South America and over 73 per cent of that felled in Asia and the Far East was utilized for firewood. The firewood situation is predicted to worsen so alarmingly that by the year 2000, even if we produce enough food to feed the world's population, there won't be enough firewood to cook it.

It is thus evident that tropical deforestation can impose severe stresses and adverse consequences on the ecosystem and the biosphere at large, and that deforestation is likely to continue if the people who are compelled to do that have no viable alternatives to meet their basic demands of food and wood. As Odum (1971) has pointed out, an ecological re-evaluation of tropical agriculture in particular, and environmental management in general, is urgent if man is to correct his past mistakes and avoid future disasters as he quite literally bulldozes his way into the jungles seeking more food and living space. The governments of these regions, confronted with mounting economic problems, cannot desist from commercially exploiting the forests to raise money for essential development, or effectively prevent the shifting cultivators and settlers from felling the forests. The new agricultural technology for increased food output is, unfortunately, not acceptable to both these farmers and their governments because of the high demand it places on costly inputs. It is therefore essential to evolve a system that would permit both forest land and marginal lands rated unsuitable for profitable production systems, to be utilized for the production of food and/or the rearing of animals, and at the same time ensure that the protective cover of forests in the tropics is maintained and/or restored. Such a system, which produces as well as conserves, is *agroforestry*.

AGROFORESTRY AS A LAND-USE SYSTEM

We have seen that agroforestry is a relatively new name coined to denote the type of land-use system that, according to King (1978), eschews the false dichotomy of agriculture and forestry, conserves the ecosystem, and at one and the same time provides food and wood. Some form of agroforestry has long been practised by many farmers, particularly those with low levels of technology and resource inputs, and in areas believed to be unsuitable for more profitable production systems. However, the people who depend on this type of "primitive" land-use system - an estimated 630 million, or 35% of the total population of the developing countries - are the poorest of the world's poor (King, 1978). Recent advances in agricultural production technologies, often collectively called the green revolution, have bypassed such people. Furthermore, agricultural scientists, in pursuit of their discipline or of commodity-oriented research, have ignored them. Agroforestry is designed primarily with these unfortunate farmers in mind - the poor who eke out a living by practising some sort of farming in the marginal lands of the tropics and sub-tropics, and who by their activities often cause considerable degradation of the ecosystems in which they operate.

CONCEPTS OF AGROFORESTRY

Since agroforestry encompasses some age-old farming practices for which modern concepts are only now being developed, a universally acceptable definition of agroforestry has not been evolved. The definition suggested in *Trees, Food and People: Land Management in the Tropics* by Bene *et al.* (1977) was later amplified slightly by King and Chandler (1978) to read as follows: "Agroforestry has been defined as a sustainable land management system which increases the overall yield of the land, combines the production of crops (including tree crops) and forest plants and/or animals simultaneously or sequentially on the same unit of land, and applies management practices that are compatible with the cultural practices of the local population". The subject was debated at a conference in Nairobi in July 1979, when various suggestions and modifications were proposed (ICRAF/DSE, 1980).

Whatever be the definition, agroforestry can best be considered as a philosophy of integrated land-use particularly suited for marginal areas and low-input systems. Like multiple cropping, it is a generic term, having various manifestations of different forms. The major specific components of agroforestry are:

Agrisilviculture - concurrent production of agricultural crops (including tree crops) and forest crops.
Silvopastoral systems - integration of silviculture with animal production, with grazing within the forests.
Agro-silvo-pastoral systems - concurrent production of agricultural and forest crops and rearing of domesticated animals; in other words, a combination of agrisilvicultural and silvopastoral systems.
Multipurpose forest tree production systems - regeneration and management of trees capable of producing useful wood, leaves and/or fruit that are suitable for food and/or fodder.

A hierarchial organization showing the components of the agroforestry systems as suggested by Torres (1980b) is given in Fig. 4. The underlying principle in all these systems is that the system should optimize the combined production of an agricultural and a forest crop and at the same time conserve and improve the site. As mentioned earlier, an analogy can be drawn between multiple cropping and agroforestry in order to make the principles and concepts of agroforestry more easily understood. Thus the "mixed cropping" and "intercropping" types of multiple cropping are similar to agrisilviculture, and these systems could be either haphazard or organized, as in multiple cropping. The sequential cropping type of multiple cropping is roughly equivalent to the planned fallow of agroforestry, which is designed to control and harness shifting cultivation and to reduce the fallow period without deterioration of the site quality. These concepts have been further elaborated by King (1980).

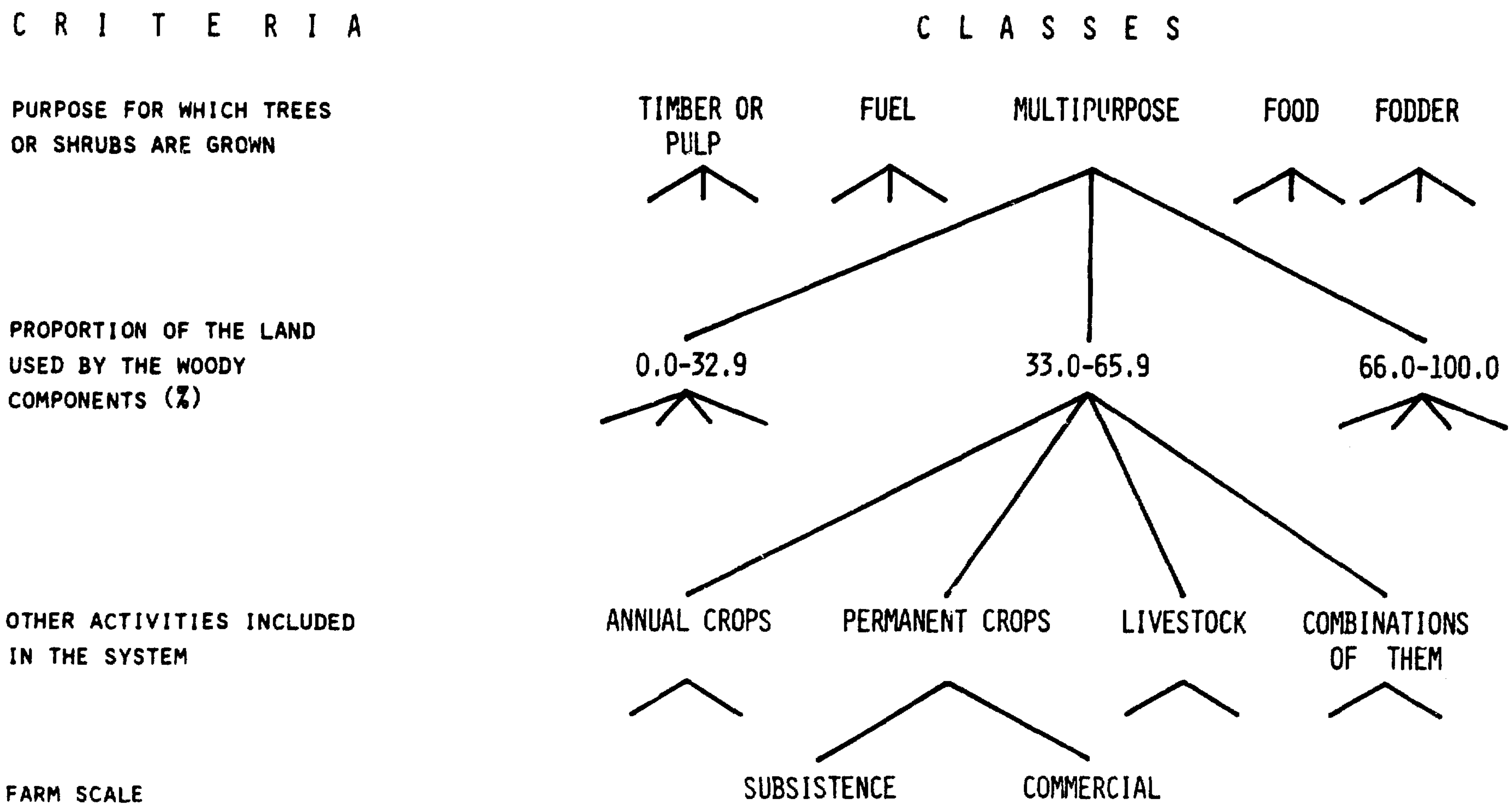

Fig. 4. Hierarchial organization of agroforestry systems (Torres, 1980a).

THE VALIDITY OF AGROFORESTRY CONCEPTS

The best test for the soundness and validity of the concepts of any land-use system is certainly its field performance, based on the results of which the concepts can be modified and the system suitably refined. However, the premises on which the concept is based and the evidence for its possibilities can be taken as strong indications of its validity until field trials demonstrate its applicability.

The premises on which the concepts of agroforestry are based are both biological and socio-economic. The biological premises include all the advantages of the forests on the soil and the environment, such as closed and efficient nutrient cycle, maintenance of organic matter, prevention of run-off and soil erosion, regulation of micro-climate, and above all the adaptability of trees to soils that are incapable of sustaining annual agricultural crops. The socio-economic factors that substantiate the potential value of agroforestry are that the poor farmers in developing countries, existing in an environment of mounting population pressure and lack of resources, are forced to utilize inherently unproductive areas for food production and practise land management systems that have disastrous consequences, such as deforestation, desertification, degradation of soils, floods and droughts. These farmers should be given the alternative of a system of land management that combines the practices of agriculture and forestry to provide food and wood without causing deterioration of the ecosystem.

The field examples that indicate the feasibility and desirability of agroforestry are many. Surveys conducted by the International Council for Research in Agroforestry (ICRAF) in 1978 indicate that some forms of agroforestry are prevalent in almost all the developing countries of the world. One prominent system is *taungya*, reported to have originated in Burma in 1856 (Blanford, 1958). The practice has since spread throughout Asia, Africa and Latin America, and is known by different names: *kaingining* in the Philippines; *ladang* in Malaysia; *chena* in Sri Lanka; *kumri*, *jhooming*, *ponam*, *taila* and *tuckle* in India; *shamba* in Kenya; *parcelero* in Puerto Rico, *consorciacao* in Brazil, etc. However, taungya is, by far, the most widely adopted term in most of these and other countries; it is a Burmese word, literally meaning hill cultivation. Many of the forest plantations in the tropics, particularly in Asia and Africa, have been established by the taungya system, which indicates that agricultural crops and trees can be grown together, at least during the initial stages of existence of a forest plantation. A second convincing example of agroforestry is homestead farming in the tropics. Highly efficient land-use systems involving orchard trees and other horticultural and annual agricultultural species are a common practice in the small farm holdings of the thickly populated tropical regions (Nair, 1979). Farmers in Central America imitate the structure and species diversity of tropical forests by planting a variety of crops with different growth habits, together corresponding to the layered configuration of mixed forests (Wilken, 1977). In addition to these, evidence accumulating from the mixed cropping of annuals and the advantages attributed to that (Papendick *et al.*, 1976) also apply, in a way, to agroforestry situations. Thus, there are sufficient grounds to assume that agroforestry might be a sustainable land-use system in fragile ecosystems.

RESEARCH IN AGROFORESTRY

Research on agroforestry systems has, so far, been almost non-existent. There are probably two reasons for this: first, the focus in agricultural science has been directed towards capital- and resource- intensive systems. Traditional farming systems that have been practised primarily in marginal and scientifically-neglected areas have not received the benefits of these innovations. Secondly, agriculture and forestry have, in the past, developed rather independently with established boundaries and with very little interaction, and as a consequence, interactive disciplines such as agroforestry were benignly neglected. However, the importance of agroforestry and other integrative land-use systems is now being increasingly realized, and the science of agroforestry is being developed.

As Nair (1980) has pointed out, the science of agroforestry is distinct from other related disciplines in that it is a "synthetic" science that draws upon and integrates different disciplines, not only of the natural sciences but also the social sciences. It is a holistic science that encompasses the integration of different disciplines to deal with supra-individual levels of organization such as a plant community, a field, a farm, a village, an ecosystem, etc. And it is teleological in nature, concentrating on goals, purposes and social objectives rather than a deterministic or mechanistic one aiming at establishing cause-effect relationships. Moreover, developmentally and operationally, the science of agroforestry is distinct in that it has originated in the tropics and sub-tropics and therefore deals with continuous growth and aseasonal production cycles. Its value is assessed not only in terms of production, but also in terms of social and economic benefits. And it is interdisciplinary in nature, so that agroforestry researchers may have to shed their conventional commodity and discipline orientation.

Since practically no research has been done to improve agroforestry systems, the research needs are many and they have to be properly programmed and assigned priorities. Testing the shade tolerance of various agricultural species; identifying suitable forest species that protect the soil and permit the growth of understorey crops; determining espacements and other management schedules for both trees and agricultural species: these are the practical problems of immediate concern. Simultaneously, investigations need to be undertaken on nutrient dynamics in agroforestry systems, the complementary and competitive interactions of species, the evolution of genotypes of trees and agricultural species suitable for agroforestry, etc.

Because of the location-specific nature of agroforestry, it may be presumptuous to make uniform recommendations for agroforestry practices and research programmes on a regional or zonal basis. Nevertheless, there are some broad general considerations that might be applicable to each zone or region. A few such generalized considerations for possible agroforestry systems and research priorities for these areas, as suggested by Nair (1980), are given in Table 4.

It may be pointed out in this context that the research methodologies and strategies in agroforestry also have to be different

Table 4. Research priorities for some potential agroforestry systems in different agro-ecological zones (Nair, 1980)

Zones and areas	Farming systems practised *	Role of trees in the system		Suggested agroforestry practices	Special priorities for research **
		Present	Potential		
Dry savannas	1. Permanent cultivation 2. Unregulated leys (semi-permanent) 3. Grazing (Semi-nomadic to ranching)	Little to moderate	Multipurpose trees for shade/fodder/fuel/food	1. Multipurpose trees and a) fodder for grazing b) food crops 2. Integration of animals	1. Agroforestry and water use efficiency 2. Efficient systems for production of food/fodder/fuel/wood
Humid lowlands	1. Permanent (rainfed) farming 2. Semi-permanent 3. Perennial crops	Little to moderate	Integration of trees in farming systems; Stabilisation of ecosystems	1. Intercropping in sparsely planted areas 2. Integration of livestock	1. Agroforestry for maintenance of soil fertility 2. Small holder technology and agroforestry
Mountain and upland ecosystems	1. Shifting cultivation 2. Unregulated leys (semi-permanent) 3. Permanent cropping (in rainfed areas)	Moderate	Increasing use of trees for soil conservation	1. Grazing in tree-planted areas 2. Soil conservation by tree planting along contours	1. Agroforestry practices for improving degraded areas 2. Soil conservation through agroforestry
Annual agricultural crop areas	1. Permanent in rainfed areas 2. Irrigated	Very little	Integration of trees in farming systems	1. Planting trees on bunds and along irrigation canals 2. Strip planting of trees in unutilized areas of agri. field	1. Role of trees in stabilising the ecosystems 2. Crop/tree interactions
Tree crop plantations	1. Permanent farming 2. Small holders 3. Estates	Major		1. Intercropping 2. Mixed cropping 3. Multistorey cropping 4. Mixed farming	1. Intensification of land use through multi-species plant communities
Forest plantations	1. Exploitation 2. Management	Major		1. Improved Taungya systems 2. Regulated management of trees	1. Improvement of Taungya 2. Development of Silvo-pastoral systems

* According to Ruthenberg's (1980) classification.

** These are in addition to the general (common) priorities for research for all zones such as identification of appropriate species, improved management techniques for polyculture, soil fertility management, etc.

from those developed for the conventional disciplines of agriculture and forestry. Some such approaches have been presented by Nair (1980), Torres (1980a) and Huxley (1980). The phases involved in agroforestry research as suggested by Nair (1980) are given in Fig. 5. Based on these considerations, Torres (1980b) has outlined the strategies and framework for research in silvopastoral systems. He argues that a balanced research strategy between "testing" a simple hypothesis and "quantifying" process rates is an appropriate strategy to be followed in silvopastoral research, and to accomplish this he has proposed a framework for research programmes aimed at improving existing systems and simultaneously looking for new woody components of the primary production system.

AGROFORESTRY AND FRAGILE ECOSYSTEMS

When discussing agroforestry, the emphasis is usually on low-input land-use systems and marginal areas. The question is often raised whether agroforestry is confined only to such areas. There is no reason why it should be, but there is a general consensus that agroforestry systems are most likely to be considered for "fragile" environments and "degraded" environmental situations, with inputs restricted by economic necessity. The bulk of tropical land is not considered suitable for the growth and production of high-yielding varieties of cereals and the application of other advanced agricultural technologies. Moreover, if sedentary agriculture is practised on these lands, they lose their ecological equilibrium and become degraded. Such areas, in which natural resources are currently being wasted either through over-exploitation, under-utilization and misuse, or through sheer neglect, have been described as *wasted lands* by King and Chandler (1978), and they have been grouped under four principal ecological zones:

(i) arid and semi-arid zones;
(ii) acid savannas of the tropics;
(iii) tropical highlands and other mountain ecosystems; and
(iv) shifting cultivation areas.

ICRAF has estimated (King, 1979) that 4900 million hectares or 65% of the land in the tropical world may be classified as

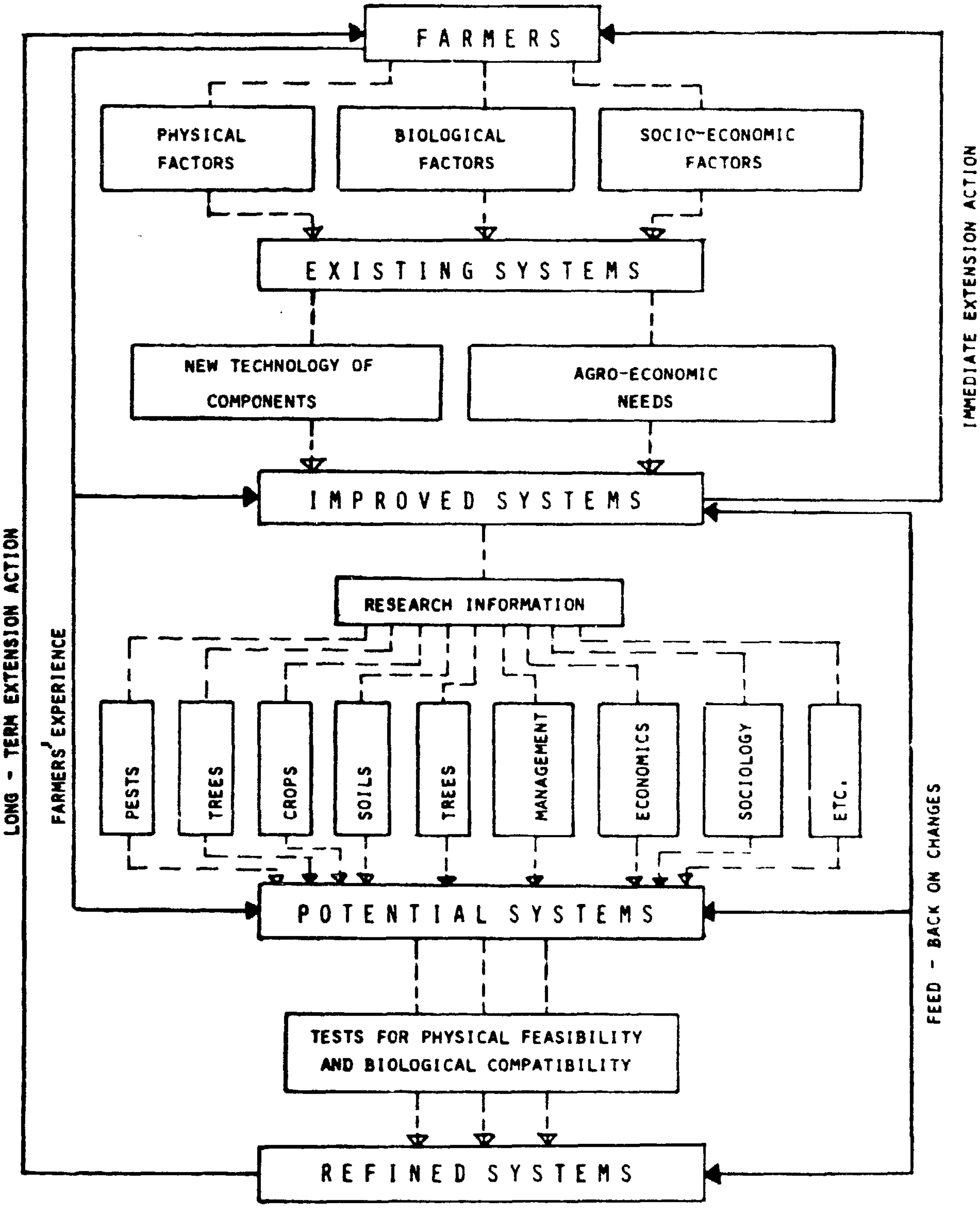

Fig. 5. A model for development and refinement of agroforestry systems (Nair, 1980).

"wasted" or as occupying fragile ecosystems. The successive degradation of these ecosystems and the role of agroforestry as a viable alternate land-use system are schematically presented in Fig. 6.

In the arid and semi-arid areas, the removal of protective trees and shrubs for fuel and shelter and the cultivation of soils that are ill-suited to agriculture, are on the increase today. Moreover, some of the intensive farming practices that have been attempted, although have increased yields in the short run, have also made the soil more vulnerable to erosion and have accelerated the rate of desertification. Agroforestry's emphasis in supporting and improving the economy of these arid zones is on (a) intensive fuelwood production; (b) integration of trees with animal production; (c) integration of trees with crop production and (d) multi-purpose trees.

The infertile acid savannas, which are found mainly in the lowland American tropics and extend over approximately 300 million hectares, are characterized by distinct dry and wet seasons with fairly heavy rainfall (1000-3000 mm p.a.) of a unimodal pattern. The population of savannas is low now, but is increasing, and the economy is based largely on cattle breeding. But the land has very low carrying capacity (8-16 ha per head of cattle) and stock farmers customarily practise rotational burning of the mature forage during the dry season. The soils are very infertile and prone to erosion (Sanchez and Tergas, 1979). The agroforestry focus on these fragile ecosystems will be on areas suitable for "natural savanna grazing" in combination with improved pastures and agriculture. The programme should consist of elimination trials of multi-purpose fodder species, introduction of selected fire-resistant fodder trees, development of live fences to assist rotational grazing, and monitoring the effect of selected shade tree groves on soil fertility and fodder quality.

The tropical upland ecosystems are being subjected to increasing rates of deforestation and degradation because of the quest for wood by rapidly growing populations and to yield land for farming. The improper land use in these highly fragile areas results in denudation of forest cover, soil erosion, silting

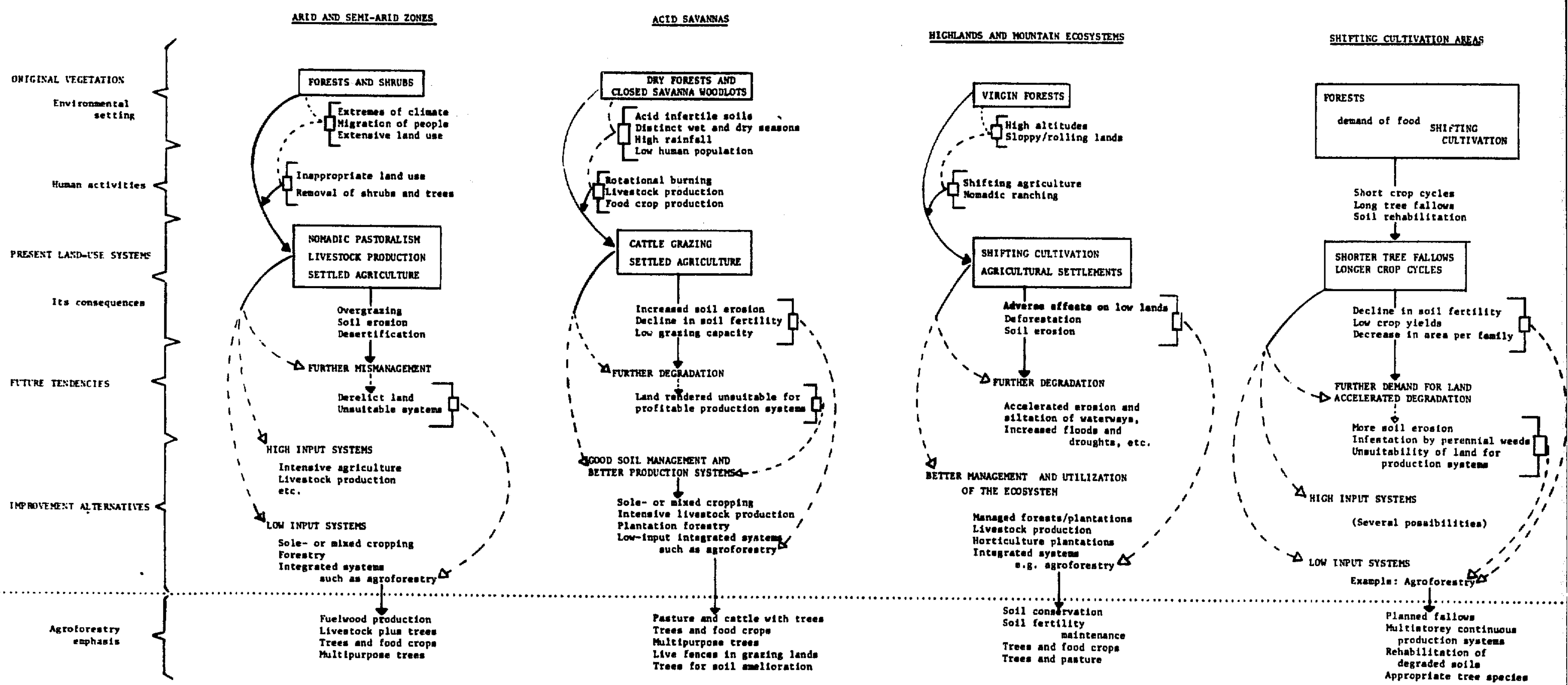

Fig. 6. Successive degradation of land in some tropical ecosystems and the role of agroforestry as an alternate land-use system for sustained productivity from these fragile ecosystems.

of rivers and reservoirs, floods, droughts, etc., which affect not only those living in the uplands but also those far away in the valleys and plains. The most glaring examples are the recurring floods and droughts in the Indian sub-continent, consequent to the ravaging of the forests in the Himalayas. Agroforestry's role in improving land use in these mountain ecosystems will consist of efficient integration of suitable tree species in the farming systems to assist in soil conservation, improve soil fertility, and provide wood, fuel and fodder.

The magnitude of the problems and the ecological hazards of shifting cultivation have already been outlined. The importance of agroforestry in providing an acceptable alternative to shifting cultivation and improving the lot of the millions who depend upon that practice is being realized. Co-ordinated action programmes in this direction should include (a) a description of traditional shifting cultivation systems and their effects on the soil; (b) testing tree fallows of controlled botanical composition; (c) espacement trials of tree planting in conjunction with crop cultivation; (d) multi-storey continuous cropping systems; and (e) regeneration of degraded soils by integrated land-use systems.

Agroforestry, however, is not a panacea for all the evils of land management in the tropics, nor is it the only or the most desirable system of land use. It is only one system that looks potentially useful and relevant to the specific conditions of the fragile environments.

SPECIES ADMIXTURE IN AGROFORESTRY

A general classification of the major components and types of agroforestry has already been presented. But the actual task of selecting the appropriate species and deciding the suitable methods to be adopted to grow the species together is really difficult - it is also the most important step in initiating agroforestry programmes. The considerations are many because of the complex and long-term nature of the programme, the multiplicity of variables, variations in the growth habits and requirements of the intended forestry and agricultural species, and other factors. Unfortunately, there is little field data from actual research, and it takes a long time to generate such data. Proposals for new programmes in agroforestry, or even for improvements in existing agroforestry-like land-use systems, have therefore to be based on existing data from studies in related land-use disciplines. Here again, there will be a substantial body of information on certain components such as the annual agricultural species, whereas the available information on other components such as woody perennials may be very meagre.

The method of admixture of the species will depend upon the species themselves, climatic conditions, the most important objective(s) of the programme, and the level of management. Some of the schemes suggested by ICRAF in the agroforestry research projects that have been prepared for a few ecological situations are summarized in Fig. 7 to indicate the range of possibilities. The schemes given here are confined to agrisilvicultural systems because agrisilviculture is the most important form of agroforestry and the patterns of agrisilviculture would also serve to illustrate the possibilities of other systems. Moreover, the schemes are only broad presentations; details concerning the species and their planting and management for each of the schemes are the subject of studies proposed for those projects. Other forms of admixture and combinations of the individual schemes mentioned here are also possible.

A. Intercropping of tree species with annual agricultural crops, both agricultural and forestry species to be planted simultaneously (or in the same season). The espacement of forestry species will vary considerably, depending upon several factors; as a general rule, the espacement will be wider in drier regions. This scheme can be also applied to agricultural plantation crops such as rubber, oil palm, etc.

B. Clearing strips of about 1 m width in primary or secondary forests at convenient intervals and planting shade tolerant perennial agricultural species such as cacao. Subsequently as the planted species grows up, the forest vegetation will be selectively thinned and in about five years, there will be a two- or three- layer canopy consisting of the perennial agricul-

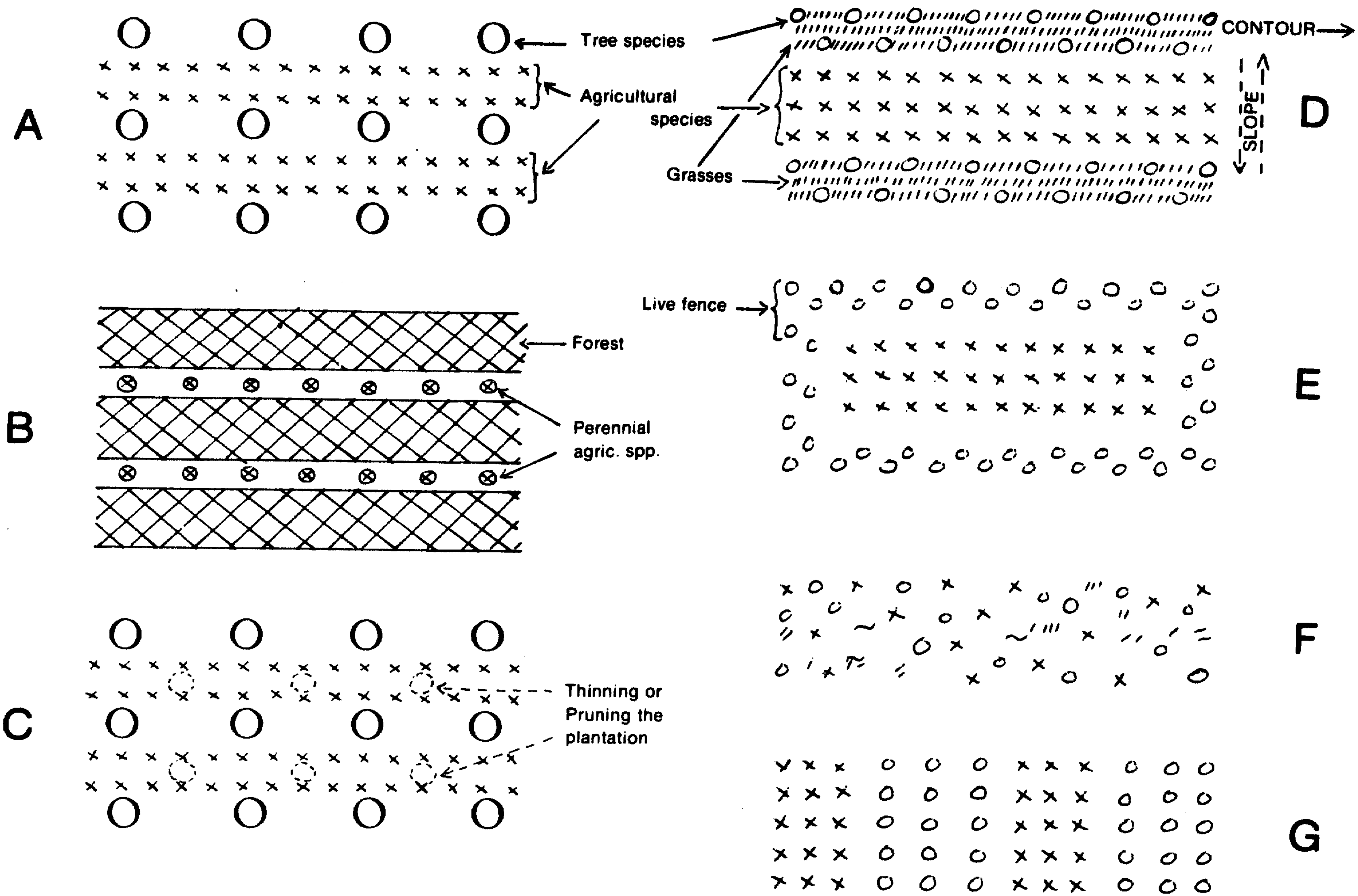

Fig. 7. Some patterns of admixture of species in agroforestry (Distances not to scale; see the text for descriptions)

tural species and the selected forestry species.

C. Introducing management practices such as thinning and pruning to existing forestry plantations, so as to allow penetration of more light to the plantation floor, and planting selected agricultural species between rows of the tree species. The extent of thinning or pruning will depend upon the tree density, canopy structure, etc.

D. In areas with sloping land, selected tree species could be planted in lines across the slope (along the contour) in different planting arrangements (single rows, double rows, 'alternate' rows), at varying distances between tree row units, and soil-binding grasses established between the trees along the contours. The area between the tree row units could be utilized for cultivation of agricultural species.

E. Close planting of multi-purpose trees around plots of agricultural fields. The trees will form live fences and wind breaks, provide fodder and fuel, and demarcate the boundaries of agricultural plots. The scheme is particularly suitable for extensive land-use areas.

F. Interspersing intensively managed agricultural areas with trees, in a regular or haphazard manner. The system is popular in smallholder farming in Asia and the Pacific, Africa and South America. Several species of plants belonging to the conventional domains of agriculture, horticulture and forestry can be seen to exist together on the same plot of land.

G. Some form of zonal planting of the different species - trees, shrubs and herbs. The width of the zones or strips for individual species will be small so that there will be some interaction between adjacent zones over a significant proportion (i.e. more than 50 per cent) of the area involved. The method is particularly suitable for the integration of herbaceous shrubs and annual agricultural species in semi-arid areas where the shrubs will provide the herbaceous plant materials that can be used as mulch in a "woody mulch farming - minimum tillage" system (Huxley, 1979).

Some examples of agroforestry-type land-use systems are shown in Fig. 8.

Fig. 8. Some examples of agroforestry land-use systems

Fig. 8a. Agroforestry in Kenya's highlands: tea in the foreground; bananas, maize and beans — bottom of slope; coffee, maize and wattle — lower slope; pasture with croton trees — mid-slope; *Eucalyptus* trees in the woodlot above.

Fig. 8b. Pasture *(Cynodon* spp.) under *Eucalyptus deglupta* in Turrialba, Costa Rica. (Photo credit: CATIE, Turrialba, Costa Rica).

Fig. 8c. Cacao under *Cassia* in the Cameroun. (Photo credit: Royal Tropical Institute, Amsterdam).

Fig. 8d. Rice intercropped with teak *(Tectona grandis)* in Indonesia.

Fig. 8e. Yams with *Leucaena leucocephala* in Nigeria (Photo credit: A.G. Seif-el-Din).

Fig. 8f. Mixed farming of 5 year-old rubber trees and broiler chicken in Malaysia. (Photo credit: Rubber Research Institute of Malaysia).

AGROFORESTRY SPECIES

The most important factor deciding the success of agroforestry is the choice of suitable species of economic plants that can be grown together. The more important among such plants are usually considered to fall under either of the two broad categories of agricultural and forestry crops - not to mention others, for example, horticultural - and though not based on any precise criteria, there is an apparent distinction between these two groups of crops. However, there are also a few less-important and relatively underexploited plants that are not so clearly classified as agricultural or forestry species. If we examine the history of the development of agriculture and forestry as separate disciplines, we notice that most of the species that were cultivated with greater managerial attention and were harvested at frequent intervals for their most important economic produce - either through repeated generations of the same short-duration species, or by repeated harvesting from the same plant - came under agriculture. Therefore, this criterion is usually implied while talking about agricultural species. However, the important point here is to determine the suitability of the species to agroforestry, no matter whether it falls under the conventional agricultural, forestry or any other group of plants.

Although as mentioned, the choice of appropriate agricultural and forestry species is important, the immediate possibility for agroforestry seems to be in introducing "agricultural" species - as understood in the common usage of the term - into existing natural and planted forests and into marginal areas where some form of native forestry vegetation already exists, rather than into areas where fresh plantations are envisaged. In the former, some of the existing forestry species will be retained while introducing agroforestry, so that the choice of "forestry" species may not be an immediate concern. Even in fresh plantations, a decision on the choice of the forestry or other perennial species would have already been arrived at before embarking on such programmes. Thus, in the initial agroforestry ventures, the choice of appropriate species which give economic yield in relatively short time span seems to be more urgent.

CHARACTERISTICS OF SPECIES SUITED FOR AGROFORESTRY

There is not yet any distinct group of agroforestry species, nor a sizeable body of knowledge on the performance of species under agroforestry-like situations (except that some species are known to grow best under trees, for example: cardamom, vanilla). Moreover, almost all of the important agricultural species have hitherto been promoted as monocrops, so that crop improvement and selection programmes have been mostly oriented towards those traits and characters that would make the improved cultivars most suited to sole crop conditions. Therefore, the agroforestry characteristics of the species are essentially speculative in nature at this stage.

In conventional intercropping in agricultural tree crop plantations, certain criteria have been suggested for choosing suitable 'subsidiary' crops. Thus Allen (1955) stated that the second or subsidiary crop grown under or between a tree crop should be tolerant of partial shade, and should not:

1. grow as tall as the main crop; its root system should exploit different soil horizons;
2. be more susceptible than the main crop to diseases they have in common;
3. demand harvesting or other operations that would damage the main crop or induce soil erosion or damage soil structure; and
4. have an economic life longer than that of the main crop.

In addition to these, Hartley (1977) adds that:

1. the soil shall be suitable for both crops;
2. the combined yield of the two crops shall be greater in monetary terms than that of the main crop when grown without the subsidiary crop; and
3. if and when the subsidiary crop comes to the end of its bearing life, the yield of the main crop shall continue at an economic level unaffected by the previous presence of the subsidiary crop.

However, experience gained from intercropping and other forms of crop combinations with agricultural tree crops indicates that it is not necessary to fulfil all these exacting requirements to have successful crop combinations (Nair, 1979). The experience from taungya and other forms of agroforestry is similar. Of course, based on the knowledge of the ecophysiological requirements of different groups of plants in general and the individual species or cultivars in particular, some predictions can be made with reasonable accuracy about the conditions that would be optimum for their best growth. Thus it would be possible to list a large number of physiological and agronomical characters that would decide the compatibility of the species in admixture, and the ability of the species to produce a reasonable yield under conditions or reduced supply of growth factors such as light and nutrients when it is grown as an understorey species. Furthermore, from the practical point of view, the ease of management of the species, its ability to withstand adverse climatic and managerial conditions, its adaptability to low-input systems and marginal areas, the marketability/local use of the produce, etc. are important considerations. But in the absence of any distinct group of agroforestry species *per se*, and the lack of extensive information on the performance of present-day cultivars of the important species under agroforestry-like situations, it is imperative to look for the species characteristics that might be relevant for agroforestry, and to exploit the relatively less-important species that show promising agroforestry potential and economic value. These considerations have to be taken into account when evaluating the agroforestry potential of the species.

AGROFORESTRY POTENTIAL OF COMMON CROPS

The agroforestry potential of a species can be defined and assessed in terms of its growth and productivity when grown under diverse agroforestry situations, which will, in most cases, be sub-optimal for the agricultural species. The manifestation of the potential of the species will depend upon environmental conditions, and as far as agroforestry conditions are concerned, there will be no uniformity with respect to these conditions; the conditions vary considerably from farm to farm. Moreover, the ultimate choice of species will depend upon the agricultural and eating habits of the farmer and the local socio-economic conditions. In general, the canopy density of the overstorey species, the rooting patterns of the different species and their phenology and branching habit, are the important characteristics in this regard. Within a given set of soil and climatic conditions, some of these, for example canopy density, depend upon management, and it is common knowledge that certain basic characters of the species that are genetically controlled are little-modified by environmental and management factors. Therefore, a number of logical steps should be followed while choosing agricultural species for agroforestry: evaluate the ecophysiological requirements for optimum growth of the species; examine their growth habits under usual cultivated conditions; assess the specific agroforestry possibilities in the situation; and compare the potential systems with any successful case studies under similar circumstances. Such information on the growth requirements and growth habits of some selected species of the major economic groups of crops have been compiled in the following section.

The species that have been selected are by no means exhaustive nor do all of them fall in the category of "agricultural" species. From the several groups of economically useful plants (cereals, pulses, tubers, oilseeds, etc.) a few species, each of which is expected to have some possibilities in agroforestry under varied climatic conditions, are selected. One of the objectives of preparing this sort of inventory for a limited number of species has been to highlight the variability in crop characteristics between the species and its consequences in relation to climatic adaptability. In addition to these widely cultivated and more researched species, there are several species that are more localized in distribution and have received little or no attention; some of them are already growing under agroforestry-like situations in their natural habitats and are of high economic value. Such under-exploited species might prove to be of great advantage in agroforestry. Short notes on 50 such species have also been included.

The criterion for assessing the performance of these species under agroforestry situations should not, however, be the yield or other measurable parameter of the individual species in comparison to that of its sole crop raised under optimal conditions, because agroforestry is designed mostly for marginal and low-input production systems. Moreover, in addition to the yield or other immediate economic gain, the long-term effect on growth and productivity of the perennial species and its effect on the soil and environmental parameters, of growing a particular species in combination with other species, is also very important. The competitive or complementary effects of the interaction of two or more species that are grown together might be different from those that would be anticipated, based on the present state of knowledge accrued from sole species populations. One good example of an unexpected complementary interaction is the yield increase of coconuts consequent to the interplanting of cacao (Nair, 1979; Nair and Varghase, 1979). Therefore, predictions about the potential of agricultural species for agroforestry situations for which no case histories are available, are speculative.

ENVIRONMENTAL ADAPTABILITY OF CROPS

Adaptation refers to a crop's ability to survive and reproduce in diverse environments. While referring to the "wide adaptability" of a species, it actually means something more than natural wide adaptation; there is a definite expectation of the performance of the species in relation to the environment. As mentioned earlier, in agroforestry, the environment involves not only the usual climatic and ecophysiological parameters but also a restricted supply of some of the growth parameters, resulting in a condition that may not be ideal for the optimal growth of certain species and cultivars. The general pattern of adaptability of the 40 selected species to specific eco-regions of the tropics is given in Fig. 9. Such a crop adaptability chart gives the optimum set of conditions for the different species and also indicates variations among the species with respect to their climatic requirements to produce economically useful yields. This variation in the environmental adaptability of species is very beneficial and advantageous in

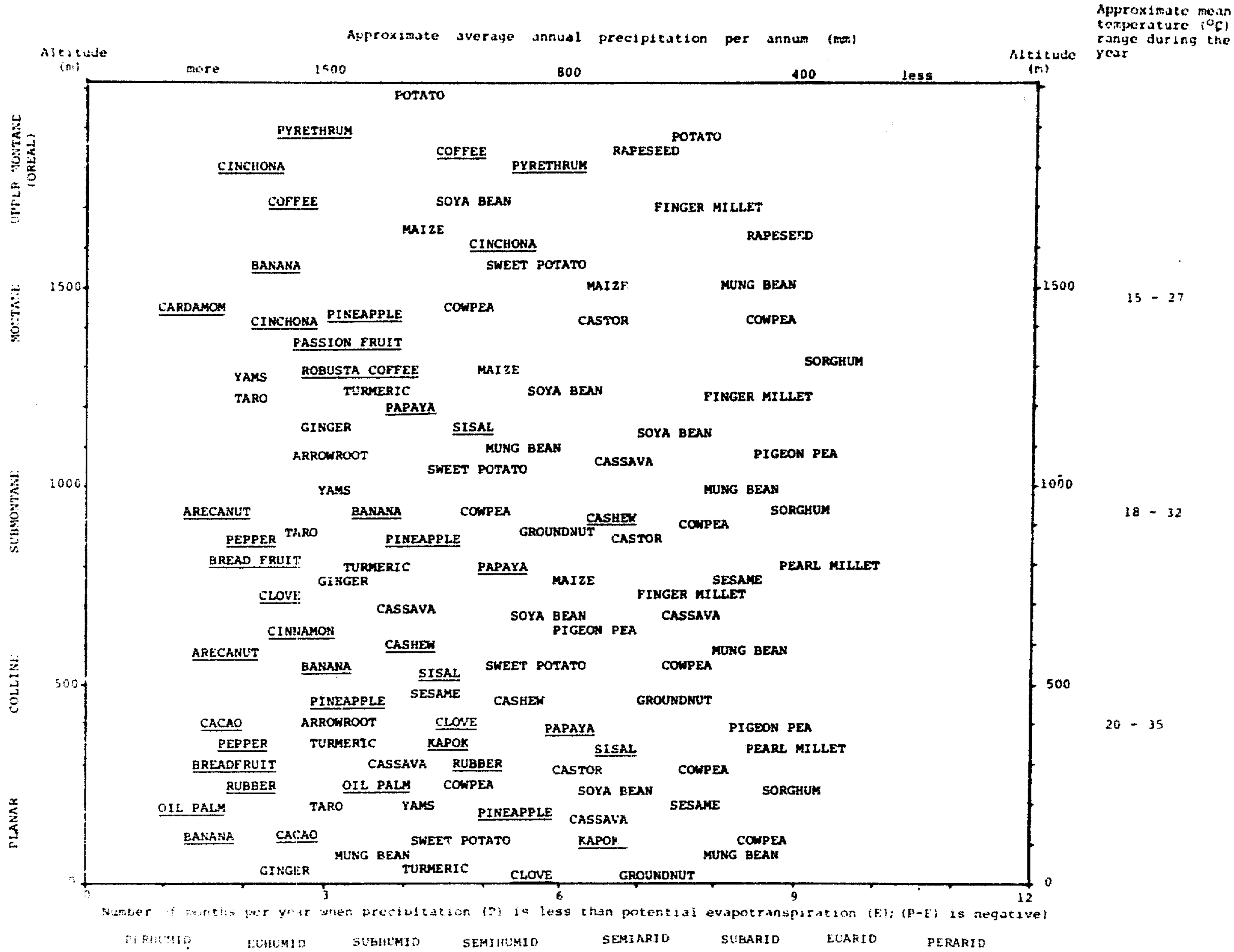

Fig. 9. Ecological adaptability of the selected species.
Perennials are underlined; species having wider adaptability are mentioned more frequently.

selecting appropriate species for varied situations. It should be noted that the environmental requirement of certain species, particularly annuals such as, say, maize or pigeon pea, is such that conditions that permit their reasonable growth can be found during at least a part of the year in many parts of the tropics. On the other hand, certain other species, such as cacao or pyrethrum have rather precise environmental requirements, so that their adaptability is restricted to somewhat limited areas within the tropics. Thus the general environmental conditions of the locality will decide the adaptability, and therefore the choice, of the species to suit that set of conditions. In order to assist in the choice of species to suit specific situations, the selected crops are also grouped (Table 5) in a very general way according to their adaptability to different ecological regions in the tropics.

The important point to be considered with respect to individual species is how far the optimal growth requirements will be satisfied in agroforestry situations and what effect the modified environment (produced by agroforestry) will have on the growth and productivity of the species. The one growth factor whose supply will be restricted most to the understorey species is light. Therefore, the growth habit of the species with respect to its light requirement will be the most important factor deciding its adaptability to agroforestry conditions. Consequently, the part of the plant that is economically useful will also have a bearing, because the grain-producing crops such as cereals and grain legumes are known to require full exposure to sunlight for optimum production. On the other hand, there are several species known to be adapted to, or tolerant of, partial shade, though to varying extents and such plants are an obvious choice for agroforestry. For the 'sun plants' also, the extent of yield reduction caused by shade will be the important factor.

Another group of plants that lend themselves to agroforestry situations are those that interact physically with other species, such as trailing or climbing species that need physical support. Most such species will also be adapted to reduced light conditions. Pepper, yams, and some of the cucurbitaceous species are good examples. The other major growth

Table 5. General grouping of the selected crops according to their adaptability to different ecological regions in the tropics

LOWLANDS (UP TO 500 m)			MEDIUM ELEVATION (500-1200 m)			HIGHLANDS (ABOVE 1200 m)		
[1]PERHUMID - SUBHUMID	[2]SEMIHUMID - SEMIARID	[3]SUBARID - PERARID	[1]PERHUMID - SUBHUMID	[2]SEMIHUMID - SEMIARID	[3]SUBARID - PERARID	[1]PERHUMID - SUBHUMID	[2]SEMIHUMID - SEMIARID	[3]SUBARID - PERARID
Arecanut	Arecanut	Cowpea	Arecanut	Arecanut	Cowpea	Banana	Banana	Cowpea
Arrowroot	Banana	Finger millet	Arrowroot	Banana	Finger millet	Cardamom	Cassava	Finger millet
Banana	Cassava	Groundnut	Banana	Cashew	Groundnut	Cinchona	Castor	Groundnut
Breadfruit	Castor	Mung bean	Breadfruit	Cassava	Mung bean	Coffee	Cinchona	Mung bean
Cacao	Cinnamon	Pearl millet	Clove	Castor	Pearl millet	Pyrethrum	Coffee	Pearl millet
Clove	Clove	Pigeon pea	Coffee-Robusta	Cinnamon	Pigeon pea	Yam	Cowpea	Pigeon pea
Coconut	Coconut	Sesame	Ginger	Cowpea	Sesame		Finger millet	Sorghum
Ginger	Cowpea	Sorghum	Papaya	Finger millet	Sorghum		Maize	Sweet potato
Oil palm	Finger millet	Sweet potato	Passion fruit	Ginger	Sweet potato		Mung bean	
Papaya	Ginger		Pepper	Groundnut			Passion fruit	
Pepper	Groundnut		Pineapple	Kapok			Pearl millet	
Pineapple	Kapok		Rubber	Maize			Pigeon pea	
Rubber	Maize		Taro	Mung bean			Pineapple	
Taro	Mung bean		Turmeric	Papaya			Potato	
Turmeric	Papaya		Yam	Passion fruit			Pyrethrum	
Yam	Pearl millet			Pearl millet			Soya bean	
	Pigeon pea			Pigeon pea			Sweet potato	
	Pineapple			Pineapple			Yam	
	Sesame			Sesame				
	Sisal			Sisal				
	Sorghum			Sorghum				
	Soya bean			Soya bean				
	Sweet potato			Sweet potato				
	Taro			Taro				
	Turmeric			Turmeric				
	Yam			Yam				

[1]PERHUMID - SUBHUMID: areas with 0-4 dry months and more than 1200 mm rain per year

[2]SEMIHUMID - SEMIARID: areas with 5-8 dry months and 500-1200 mm rain per year

[3]SUBARID - PERARID: areas with more than 9 dry months and less than 500 mm rain per year

A month is considered 'dry' when the potential evapotranspiration is more than the precipitation received during the month.

habit of importance in this context is a desirable rooting pattern. However, the criteria for desirability will depend upon the circumstances, such as the rooting pattern of the companion species, environmental conditions, etc. In certain situations a superficial or restricted root system with minimum spreading will be ideal, whereas in other situations (such as, say, drier regions) an extensive root system will be preferable. The ideal rooting configuration will, therefore, be situation-specific. An example of a desirable rooting configuration in a poly-culture with coconut palms has been presented and discussed by Nair (1979).

Thus, within the climatically determined range of adaptability of a species to a locality, the major considerations for determining its suitability to agroforestry are its adaptability to shade, ability to give a reasonable yield under sub-optimal conditions, and special growth habits (if any) that necessitate its cultivation along with other species. The 'Crop Sheets' presented in the following sections have been compiled with this in mind.

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PART II

CROP SHEETS OF SOME SPECIES OF THE MAJOR ECONOMIC GROUPS OF CROPS

CEREALS

FINGER MILLET

SCIENTIFIC NAME	*Eleusine coracana (L.)* Gaertn Family *Gramineae* 2n = 36
COMMON NAMES	Finger millet (E) Coracan (F) Coracan (Sp) Ragi (India) Wimbi (Swahili)

USES AND ECONOMIC IMPORTANCE

Finger millet is an important cereal crop and staple food in parts of East and Central Africa and in the southern parts of India. It is usually converted to flour and made into cake, porridge, pudding or gruel, and eaten with other foodstuffs. It is also used for malting and brewing. The grain is nutritious and is considered good for infants and invalids. Its great advantage is that the grain can be stored without insect damage for several (up to 10) years.

ORIGIN AND DISTRIBUTION

Supposed to have originated in India or in East Africa; is now cultivated mainly in these regions.

PLANT CHARACTERISTICS

A profusely tillering grass-like plant, of 3-6 months duration, growing up to 1 m in height. It has a shallow, branched, fibrous, adventitious root system from the base of the main stem. The stem is noded, slender (4-12 mm thick), erect and smooth and covered by the leaf sheath; leaves are 30-75 cm long and often folded though with strong midribs.

The inflorescence is terminal and consists of 4-6 digitally arranged sessile spikes, curved to inside and compact, often with an additional one or two spikes below the terminal whorl. Each spike has about 60-80 spikelets arranged alternatively in two overlapping rows towards the outer sides of the spike. Flowers are hermaphrodite and almost entirely self-pollinated within about 8-10 days. Flowering takes place from top to bottom in the spike, but in the reverse direction in the spikelets. Seeds are very small, about 1-2 mm in diameter.

A number of cvs have been recognized, and many improved cvs have been selected and bred in India, for earliness in bearing as well as for higher yields.

ECOLOGY

CLIMATE Finger millet is one of the hardiest crops suited for dry cultivation in areas with annual rainfall of 700-1200 mm. It does not tolerate heavy rainfall, and it requires a dry spell at the time of grain ripening. However, the crop requires a well-distributed rainfall during the vegetative stages. It grows best in areas at 1000-2000 m altitude with average maximum temperature about 27°C and average minimum above 18°C.

SOIL In India, finger millet is cultivated mostly in red lateritic loams. Relatively fertile and free-draining soils are the most suitable.

PHYSIOLOGY AND COMPOSITION

Finger millet is a short day plant with an optimum of 12 h photoperiod. Photoperiod and temperature influence the time to maturity. While it does not tolerate waterlogging, it can tolerate dry spells during the early stages of growth.

The grains contain an average of 8% protein, 72% carbohydrate, 3% fibre and 2.7% ash. The protein of the grain is of good biological value, and the grain is a good source of calcium.

AGRONOMY

CROPPING SYSTEM In India, finger millet is grown in 2-3 year rotations with many other crops such as millet, pulses, groundnut, maize, tobacco, vegetables, etc. depending upon the locality. It is also grown as an irrigated crop all the year round, and as a mixed crop with pigeon pea, sorghum, etc. A system of "ash culture" known as *citemene* cultivation is practised in the infertile soils of northern and central Zambia. It consists of raising a broadcast crop of finger millet in the ash obtained by burning the trees and woodlands.

PROPAGATION By seed; seeds germinate quickly.

LAND PREPARATION A clean, friable and smooth seedbed is required for even distribution and coverage of the small seeds and to avoid competition from weeds. Farmyard manure is incorporated into the soil at the time of seedbed preparation.

SOWING The seeds may be broadcast or drilled about 2.5 cm deep in lines about 20-25 cm apart; or 3-4-week-old seedlings are transplanted, under irrigated conditions, at 15 x 20 cm spacing. About 30 kg seeds are required for broadcasting in one hectare, whereas for drilling, less than 10 kg/ha are required.

AFTERCARE Thinning the stand to 10-15 cm between plants when the plants are 3-5 cm high, and weeding are important operations. The first weeding is done along with thinning, which is followed by one or two more (hand) weedings. Thorough seedbed preparation reduces the incidence of weeds, but drilling in rows is preferred because weeding in the broadcast crop is more difficult than in the line-sown crop. *E. africana* and *E. indica* are the common weeds and they occur in large numbers because during the early stages of growth they look similar to finger millet.

MANURING It is a usual practice to apply large quantities (20-25 t/ha) of farmyard manure. Ferilizer trials have shown good response to nutrients, especially N. Depending upon moisture conditions, soil type and cultivar of the crop, fertilizer recommendations vary from 25-90 kg N, 20-40 kg P_2O_5 and 45 kg K_2O/ha. Fertilizers are given as basal dressing except N, which is given in two equal instalments, one before sowing and the other when the plants are 6 weeks old.

HARVESTING The crop matures in 3½-6 months, depending on the cv. and location. In India, the plants are cut close to the ground, tied into sheaves and stacked to dry, and threshed by beating with sticks or trampling by oxen or by stone rollers. In Africa, individual heads are cut with hand-knives with small portions of straw attached; the heads are piled in heaps and then threshed by beating with sticks or rubbing between two stones. The crop does not attain maturity simultaneously, especially under irrigated conditions, when frequent harvestings may be necessary. Combine harvesting is also possible.

YIELD

Average yields of rainfed crop vary from 700-1000 kg/ha; irrigated crop yields double the quantity; still higher yields, up to 5000 kg/ha, have been obtained.

PESTS AND DISEASES

The crop is relatively free from damage by pests and diseases, but the fungus *Piricularia* sp. causes leaf and head blasts, the hairy caterpillar *Amsacta albistriga* eats the vegetative tissues, and birds cause damage during the ripening stages of grains.

AGROFORESTRY POTENTIAL

The crop is useful for agroforestry because of its hardy nature and short duration and is valuable as a "catch crop" before or at the time of starting new plantations.

MAJOR RESEARCH INSTITUTIONS AND REFERENCES

Agricultural universities in Bangalore and Hyderabad, India, conduct research on finger millet, and the research results can be found in Indian research publications.

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CEREALS

MAIZE

SCIENTIFIC NAME	*Zea mays* L.
	Family *Gramineae*
	2n = 20
COMMON NAMES	Maize, corn (E)
	Maïz (F)
	Maiz (Sp)

USES AND ECONOMIC IMPORTANCE

Next to wheat and rice, maize is the most important cereal in the world and is one of the highest yielding of all grain crops. It is a staple food, particularly in the tropics; is used as a livestock feed especially in temperate and advanced countries, and is a raw material for many industrial products such as starch, syrup or sugars, oil, alcohol etc. Over 500 important products and byproducts are reported to be obtained from maize.

ORIGIN AND DISTRIBUTION

Maize is believed to be a native of southern Mexico. It is now cultivated throughout the world in areas with suitable growing conditions. The major producer is the USA, which accounts for 60% of the maize of international trade. However, most of the maize produced is consumed locally. It is the leading crop of the USA and a staple food in East Africa and many tropical regions.

PLANT CHARACTERISTICS

Maize is an annual grass. It is usually single-stemmed but sometimes produces tillers, and grows up to 4 m tall.

The adventitious roots develop about two weeks after germination, during which period the seminal roots are present. Roots are profusely branched and grow both vertically (up to 2 m) and horizontally. Roots also grow from the lower nodes above ground level. These are called prop roots and they lend some support.

The stem is solid, usually 2-3 m high and 3-4 cm in diameter with 8-20 clearly-defined nodes. Internodes are shorter and stouter at the base. Buds in the axils of the leaves of the three lowest internodes may produce tillers, but this is not a preferred character.

Leaves are alternate, produced on either side of the stem at the nodes. Leaf sheaths, usually with hairs along the upper margins, enclose internodes for varying distances. The leaf blade is linear-lanceolate; 30-150 x 5-15 cm.

Both male and female inflorescences are produced separately on the same plant. The male inflorescence, called 'tassel', is a terminal panicle, about 40 cm long, with a central axis as the continuation of the stem and several erect or flexuous lateral branches. Paired spikelets are borne in rows on the main axis and branches, each spikelet has two glumes of equal size, and two staminate flowers within the glumes.

The female inflorescence called the 'ear' is a modified spike, produced from a short lateral branch in the axil of one of the largest leaves in the middle of the stem. The ear has a central axis or cob, which is a thickened modified stem protected by 8-13 modified leaves from the lowest internode of the ear-bearing lateral branch, and these modified leaves become the husks of the cob. The cob bears paired spikelets in longitudinal rows. Each plant usually produces only one ear, but sometimes two or three. The fruit, known as kernel or 'grain' is a caryopsis which matures in about 50 days after fertilization. A mature cob is 8-40 cm long, 3-7.5 cm in diameter, and contains 300-1000 grains arranged in an even number of rows varying from 4 to 30 along the length of the cob.

The kernel consists of a short spongy pedicel or tip, a smooth pericarp or hull which constitutes about 5.5% of the kernel, the endosperm (*c.* 82%) and an embryo (*c.* 11.5%), which lies to one side of the base of the seed and is rich in fat, protein and minerals.

Self-pollination takes place only up to about 5% in maize, because it is protandrous - the pollen sheds before the silks are receptive. The tassel sheds its pollen within a period of over a week and the pollen remains viable for about 24 hours, viability being less in hot dry weather. The pollen is produced in enormous quantities: about 2-5 million grains per tassel. The silks emerge during a period of 3-5 days and remain receptive for about 14 days.

The time to maturity of the crop varies greatly according to variety and altitude. At low altitudes and warm climates, it flowers in two months and matures in four, whereas at higher altitudes and colder climates, it takes about 6 months to flower and 9-12 months to mature.

Maize is the crop that has been subjected to maximum genetic and cytogenetic studies. Consequently tremendous advancements have been attained in improving the crop. Mass selection, hybridization, use of inbred lines, exploitation of cytoplasmic male sterility, development of synthetic cultivars etc. are the methods employed to develop strains for higher yield, adaptation to specific conditions, time to maturity, response to soil fertility conditions, tolerance of drought, pests,diseases, and adverse soil conditions, ear characters, chemical composition etc. Thus, the type of cv. grown or recommended will depend upon local conditions. In low input systems of agriculture, a synthetic cv. is preferable as it permits using seed from one crop to the next.

ECOLOGY

CLIMATE Strains or cvs of maize adaptable to a wide range of ecological conditions are available. However, it is essentially a crop of the warmer parts (seasons) of temperate regions and the humid tropics. It is not suited to arid conditions and ever-wet tropical evergreen forests. It is grown from sea level to about 3000 m altitude and from 50°N to 40°S of the equator. The optimum temperature for germination is 18-21°C and for tasselling, 21-30°C. In the tropics, maize grows best in areas with rainfall of 600-900 mm during the growing period, but also grows in areas receiving as low as 200 mm during the growing period. The young maize plant is moderately drought-resistant, the most critical period being the 30 days of maximum growth before pollination, when the weather should be warm and wet, with at least 100-125 mm of rain. The crop does not tolerate frost and waterlogging.

SOILS Maize prefers well-drained and deep soils, well-supplied with plant nutrients. It is highly susceptible to waterlogging; the crop can be killed if it stands in water for as long as a day. It can be grown on soils with a pH from 5.0-8.0; but 6.0-7.0 is optimum.

PHYSIOLOGY AND COMPOSITION

Maize is next only to rice in its eco-physiological adaptability; for optimum growth it requires full sunlight, but under subsistence farming conditions and in homestead gardens, it is grown under partial shade. Maize is a plant with very fast rates of growth and photosythetic production during vegetative stages.

Maize grains at harvest contain 20-30% moisture, but before storage, the moisture content is brought down to below 13%. On dry-weight basis, the grain contains about 77% starch, 9% protein (varying from 6-15%), 5% fat and 2% ash.

AGRONOMY

CROPPING SYSTEM Maize is grown mostly as a sole crop, in rotation with other cereals, legumes, potatoes, sugarcane etc. It is also grown mixed with legumes and low-growing vegetables. In Africa, many peasants still grow much maize by shifting cultivation and the 'shamba' (taungya) system.

PROPAGATION Always by seed; in moist warm soils, germination takes place in 3-5 days after sowing, when the plumule breaks through the seed. The coleoptile emerges from the soil 6-10 days after planting.

LAND PREPARATION Thorough cultivation is generally practised to give a fine seedbed free of weeds and with good crumb structure. But of late, the tendency is to minimize the tillage operations to reduce the cost of cultivation and minimize soil erosion.

SOWING Maize is sown by hand in peasant farming in the tropics, and mechanically in commercial cultivation. Depth of planting is 5-12.5 cm depending upon climate, soil type, etc. Seeds are sown deeper in dry soils. Maize is usually sown early in the season, immediately after the danger of frost is over in temperate regions, and at the beginning of the rainy season in the tropics. It may be planted on ridges or hills or in rows. The spacing will depend upon the local climatic conditions and the cv. The usual row spacing is 75-100 cm and about 30 cm between plants, giving a stand of 50,000 plants/ha, for which the seed rate is 9-16 kg/ha. In drier areas, the spacing is wider. When sown by hand, the plant population is adjusted to the required level by thinning, when the plants are about 15 cm tall.

MANURING Maize is a heavy feeder and requires high quantities of nutrients, especially nitrogen, the amount being dependent on the soil conditions, cv., etc. Fertilizer rates as high as 200 kg N/ha have been recommended. For best results, nitrogen is applied in three equal instalments at the time of sowing and one and two months after planting; sometimes two-thirds of the total quantity of nitrogen is given when the plants are knee-high. In commercial production, P and K, and secondary and micronutrients are also given, especially sulphur and zinc; but in tropical Africa, response to P is variable and there is little or no response to K.

AFTERCARE During the pre-tasseling period, which varies from 50-75 days depending upon genetic and environmental factors, the crop is kept weed-free either by hand-weeding and inter-cultivation or by the use of herbicides.

HARVESTING Maize grain is physiologically mature about 8 weeks after flowering when the grain contains 35-40% moisture. When fully mature, the leaves become yellowish and the husks papery, and the grains will be hard and shiny in appearance. The cobs are left to dry to about 25% moisture for combine harvesting and about 15% for hand harvesting.

When harvested by hand, the cobs are removed with as little stalk attached as possible. The grains do not shatter. For proper storage, the moisture content of the grains has to be reduced to 12-13%, which is usually done by sun drying. Cobs are stored in cribs made of wire mesh, or grains are stored in simple granaries. The shelling percentage is 70-80%.

YIELD

Yields vary greatly; average yield in tropical regions is about 1500 kg/ha; under good management, the yields are from 3000-5000 kg/ha. In the corn belt of the USA, they are much higher.

PESTS AND DISEASE

Stem borers belonging to the genera *Busseola, Chilo, Diatraea* and *Ostrinia*, corn earworms *(Heliothis* spp.), cutworms and army-worms are the major insect pests. The major fungal diseases are leaf blight *(Helminthosporium turcicum*, also known as *Trichometasphaeria turcica)*, downy mildew *(sclerospora* spp.), and smut *(Ustilago* and *Sphacelotheca)*. Stored grains are attacked by moths and weevils, and by rats, squirrels and other rodents.

AGROFORESTRY POTENTIAL

Maize has replaced sorghum and other millets in areas with more assured rainfall in many parts of the world because maize yields more grain per unit area, requires less labour to grow and is easier to store, and because cvs with varying agronomic characters and adaptability to varied conditions are available. However, substitution of maize in borderline areas may be disastrous in years with unfavourable climate. The widespread preference for maize in varied climatic and agronomic situations sometimes makes it imperative to grow maize in areas that are less than ideal. This is often the case when it is used in agroforestry.

MAJOR RESEARCH INSTITUTIONS AND REFERENCES

Because maize is perhaps the most intensively researched food crop, research reports relating to it appear in almost all agricultural research journals and publications from all parts of the world. All the major maize-growing countries have their own national research and development programmes. CIMMYT, the

International Wheat and Maize Research Center in Mexico, is the leading international centre.

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Fig. 10a Maize with *Cupressus lusitanica*, Kenya.

Fig. 10b. Maize and beans with *C. lusitanica*, Kenya.

Fig. 10c Maize and beans under *Eucalyptus saligna*, Kenya.

Fig. 10d **Maize and *Leucaena leucocephala*** — Alley cropping. (Photo credit: B.T. Kang, IITA, Nigeria)

PEARL MILLET

SCIENTIFIC NAME	*Pennisetum glaucum* (L.)
	syn: *P. typhoideum* Rich
	P. typhoides (Burm. f.) Stapf & Hubbard
	Family *Gramineae*
	2n = 14
COMMON NAMES	Pearl millet, bulrush millet, spiked millet, cat-tail millet (E)
	Millet perlé, petit millet (F)
	Mijo perla, panizo (Sp)
	Bajra (India)

USES AND ECONOMIC IMPORTANCE

A major food crop in the drier parts of tropical world, especially in India (where it is the fourth most important cereal after rice, sorghum, and wheat) and the northern territories of West Africa. It is consumed mostly after husking. It may be cooked in the same way as rice, or ground into a flour and made into a porridge. The grain may be fed to poultry and other livestock or used to produce malt; in Africa, the malted seed is an important source of beer. The green plant is a good fodder. The straw, which is inferior to other cereal straws as a cattle feed, is also used for bedding, thatching, fencing and fuel.

ORIGIN AND DISTRIBUTION

Considered to have originated in western tropical Africa. The major producing regions are India and tropical Africa - especially in the Sahel and Sudan zones. It is not a crop of international trade.

PLANT CHARACTERISTICS

An erect tillering annual usually 1-2 m high, but grows as high as 3.5 m. Has a single seminal root, followed by fibrous adventitious roots from lowest nodes of stem and tillers. Solid, slender stem; prominent nodes with a ring of silky hairs; leaves in 2 vertical rows on either side of stem; 30-100 cm long and 0.5-5.0 cm broad leaf blade. Inflorescence is a contracted panicle or false spike, resembling a bulrush, and is terminal, dense, 15-140 cm long, cylindrical, 1-4 cm in diameter. Spikelets usually borne in pairs, two-flowered, 3-9 mm long, lower floret usually male. Fruit is a caryopsis, small, usually obovoid or elliptic, about 4 mm long, white, yellow or grey in colour. The plant is markedly protogynous and cross-pollinated.

The spike emerges about 10 weeks after sowing and the grain begins to develop about a week after, and is fully developed about 30 days later. Thus the total duration of the crop is about 4 months.

A number of races and cultivars are recognized in Africa and India. Based on the total duration of the crop, these are short- (80 days), medium- (100 days) and long- (150 days) duration types. There is considerable variation in most cultivars as a mixture of cvs is usually planted and the crop is cross-pollinated. High-yielding hybrids have also been evolved.

ECOLOGY

CLIMATE Pearl millet is relatively drought-resistant and suited to drier and sandier regions than sorghum, but it requires a certain minimum amount of moisture for growth as it does not remain dormant during periods of drought. Early-maturing cultivars are found in lowest rainfall areas and late-maturing ones in areas with more rainfall. The northern limit of pearl millet in West Africa is about 250 mm isohyet. Even distribution of rainfall is more important than total precipitation.

SOILS It can be grown on a variety of soils, but light loams are preferred. Its merit is that it can give economic yields in sandy and poor soils that are too poor for other cereals except a few minor millets.

PHYSIOLOGY AND COMPOSITION

It does not withstand waterlogging. It is tolerant of weed competition and comparatively free from *Striga hermontheca*, the parasitic weed, whereas most other cereals are susceptible to it. Its most serious disadvantage is its susceptibility to bird damage.

The grains contain approximately 12.4% water, 11.6% protein (high in tryptophane and cystine, but low in lysine and methionine), 67% starch (composed of amylopectin and amylose in 2:1 proportion), 1.2% fibre and 2.7% ash.

AGRONOMY

CROPPING SYSTEM Usually grown as a rainfed crop, but sometimes as an irrigated crop also (in India). Mostly grown in sole stands, but also grown on ridges, with sorghum in the furrows between the ridges; also grown mixed with pulses.

PROPAGATION Always by seed; under favourable conditions, the seeds germinate about five days after planting.

LAND PREPARATION Deep preparatory cultivation does not seem necessary, and the land is usually not in a workable condition towards the end of the dry season when the crop is sown. The crop may be grown on the flat or on ridges.

SOWING Broadcast or drilled. Very rarely, 3-week old seedlings are transplanted.

SEED RATE/SPACING 3-9 kg seeds/ha; when drilled, rows are about 75 cm apart; wider spacings are compensated by increased tillering.

NUTRITION Good response to N, and P in the presence of N. Farmyard manure is the most commonly applied manure. 20-25 kg N/ha and 10-15 kg P_2O_5/ha increase the yield up to 50%.

AFTERCARE Profuse tillering suppresses weed growth, but weeding is necessary in the early stages.

HARVESTING Harvested by cutting off the heads when the grain is fully ripe. If tillers ripen unevenly, more than one harvest may be necessary. Ears are threshed by beating with sticks or treading by cattle. Fodder crop is usually harvested at milk stage. The seeds store well; they are usually consumed locally.

YIELD

Africa: 250-270 kg/ha

India: Rainfed: 700-1200 kg/ha
Irrigated: up to 2000 kg/ha

PESTS AND DISEASES

Susceptible to bird damage; also fungus diseases; downy mildew *(Sclerospora graminicola)* and smut *(Tolyposporium penicillariae)* are major diseases.

AGROFORESTRY POTENTIAL

Because of its adaptability to marginal areas (poor soils and drier areas) the crop has good potential for agroforestry in such areas. It is grown under *Acacia* spp., Baobab *(Adansonia digitata)* and other trees in West Africa.

MAJOR RESEARCH INSTITUTIONS AND REFERENCES

ICRISAT, Hyderabad, India.

Many Agricultural universities of India.

S.R.A. de Saria and S.R.A. de Farako, Upper Volta.

Bourke, D. O'D. 1963. The West African millet crop and its improvement. Sols Afr., 8, 121-132.

Ferraris, R. 1973. Pearl millet *(Pennisetum typhoides)*. Review series No. 1/1973. Commonwealth Bureau of Pastures and Field Crops, Hurley, Maidenhead, U.K.

Krishnaswamy, N. 1962. Bajra. Indian Council of Agricultural Research, New Delhi.

Fig. 11 Pearl millet with *Acacia albida*, Senegal.

Fig. 12 Finger millet (Photo credit: Centre d'Etude de l'Azote, Zurich).

Fig. 13. Sorghum under *Acacia albida*, Upper Volta

CEREALS

SORGHUM

SCIENTIFIC NAME

Sorghum bicolor (L.) Moench
syn. *Andropogon sorghum* (L.) Brot
Sorghum vulgare Pers.
Family *Gramineae*
2n = 20

COMMON NAMES

Sorghum	(E)
Sorgho	(F)
Sorgo	(Sp)
Great millet, sorgo or milo	USA
Jowar or cholam	India

USES AND ECONOMIC IMPORTANCE

Sorghum can rightly be termed the staple food of the people in the relatively drier parts of the tropics and subtropics. It is the world's fourth most important cereal crop (after wheat, rice and maize). The grain is ground into a flour that is used for a variety of preparations; it may be cooked like rice; it is used for brewing beer especially in Africa; and it is a valuable cattle feed in developed countries. The plant residues and stems are used for fuel and sometimes for thatching huts.

ORIGIN AND DISTRIBUTION

Sorghum is supposed to be a native of Ethiopia or Northeast Africa. It is now cultivated in over 50 million hectares throughout the warmer parts of the world. China, India, East Africa, the drier parts of West Africa - especially Nigeria - and the USA are the principal producers. In certain wetter parts, maize is replacing sorghum as the staple cereal.

PLANT CHARACTERISTICS

Sorghum is a vigorously-growing, single-stemmed but tillering annual grass, 0.5 to 5.0 m in height. Adventitious roots are produced from the lowest nodes of the stem; roots are much branched and they occupy the soil more fully, mostly to about

1 m depth and 1.5 m lateral spread. The stem is solid, erect, 0.5-3 cm in diameter, noded, each node having a leaf; height of stem and number of nodes variable. Leaves vary from 7-20 in number, erect when young, alternate in two ranks, lamina lanceolate, 30-135 x 1.5-1. cm, midrib prominent. The panicle is terminal, may be erect or goose-necked, densely packed with conical and short or long with primary, secondary or tertiary branching. The spikelets are borne in pairs, one of which is sessile and hermaphrodite and the other pedicelled and sterile or male. The inflorescence begins to flower when elongation of the peduncle is completed; opening of flowers begins at the top and continues downwards and is completed in 6-10 days. Flowers remain open for about 2 hours in the forenoon; pollination occurs from stamens in the same flowers, from other flowers of the same inflorescence or from other inflorescences (by wind). Usually about 5% cross-pollination, but as high as 25% in cvs with open panicles. The fruit is a caryopsis; it matures within about 30-70 days after blooming. The grain is partially covered by glumes; awns may be present or absent; the seed coat varies in colour from pale yellow to various shades between brown and red.

The crop matures in 2½ to 9 months depending upon the cv. and climatic and soil conditions.

A considerable amount of breeding and selection work has been done with sorghum. Moreover, sorghum is an extremely variable crop with a large number of cvs and varieties of different characteristics which cross readily. Selection, hybridization, exploitation of cytoplasmic male sterility, polyploidy etc. are the methods used in improvement, and the main improvement objectives are yield, time to maturity, plant height, palatability, adaptation to mechanical harvesting, resistance to pests, diseases, weeds, lodging and shattering, etc.

ECOLOGY

CLIMATE Sorghum is essentially a plant of hot and warm localities. It can tolerate drought and dry conditions, but can also be grown in areas with high rainfall and occasional waterlogging. The optimum temperature for growth is 30°C and it needs about 250-400 mm rainfall during the growing period. Being a crop of the warm regions, sorghum is usually cultivated in lower elevations, but high altitude cvs have also been developed. Sorghum does not tolerate frost.

SOIL Sorghum can tolerate a wide range of soil conditions. It grows best on reasonably fertile soils, but also grows well on heavy soils or on light sandy soils, in the pH range of 5.0 to 8.5. It will produce a crop on soils too poor for other crops.

PHYSIOLOGY AND COMPOSITION

The greatest physiological adaptability of advantage of sorghum is its resistance to drought as well as occasional waterlogging. The drought resistance is due to a very efficient and well-branched root system which develops quickly before the above-ground parts, silica deposits on the roots, lesser leaf area (compared to maize), waxy coating on the leaves, its ability to remain dormant during adverse periods etc. In areas with more favourable growing conditions, maize is a better crop than sorghum, but under marginal conditions maize may be a disaster whereas sorghum will give a crop.

Sorghum is a short-day plant, but cvs vary in their sensitivity to photoperiod. However, the length of the growing period is determined by the interaction of genotype, photoperiod, and temperature.

The air-dried sorghum grain contains 8-15% protein, 2-5% fat, 68-74% carbohydrates, 1.3% fibre, 1.5-2% ash and 8-16% water. Lysine and methionine are the most limiting aminoacids. Sorghum shoots contain the cyanogenic glycoside dhurrin, which on hydrolysis produces HCN which is toxic in concentrations more than 750 ppm. The quality of HCN varies with cv. and growth conditions; fresh growth contains more. HCN is destroyed when fodder is made into hay or silage.

AGRONOMY

CROPPING SYSTEM Usually grown as a rainfed crop, but also grown with irrigation especially in parts of India, Sudan and the USA. Grown in rotation with other crops, mainly cotton, groundnut, finger millet, tobacco, pulses, etc. Continuous cultivation in the same plot leads to heavy infestation of the parasitic weed *Striga*. It is believed that sorghum depletes the soil of fertility ("sorghum injury"), probably because of the high sugar content of its voluminous roots and depletion of soil moisture. So it is usually the preferred crop in soils depleted by previous croppings. Also grown in admixture with other crops.

PROPAGATION By seed. Properly stored seeds remain viable for long periods. Usually no dormancy; germination within about seven days after sowing.

LAND PREPARATION When grown after other crops or in the second rainy season, land preparation is not very difficult. Since the seeds are rather small, a firm fine seedbed is desirable, but in peasant farming this is seldom attained. Being a heavy feeder, sorghum should have a heavy dressing of farmyard manure, which is usually incorporated into the soil at the time of seed-bed preparation.

SOWING Sown broadcast (4-10 kg seeds/ha) or dibbled in rows about 60 cm apart. When grown as a fodder crop, seed rate is higher (about 50 kg/ha) and seeds are broadcast. Before sowing, seeds are treated with sulphur to protect the plants from smut disease. Time of sowing depends on the conditions; in dry regions, the crop is sown at the time of onset of first rains. When grown in pure stand, 60-90 x 50-20 cm spacing is adopted depending upon moisture availability and soil fertility.

NUTRITION Sorghum responds well to manures. Depending upon moisture availability, 20-45 kg N/ha and about half that amount of P_2O_5 are recommended in addition to the liberal application of organic manure. Nitrogen is given in two instalments, half as basal dose and the other half at the time of flowering.

AFTERCARE Thinning and first weeding are done with hand-hoes about 2 weeks after sowing. Subsequent weedings, especially to control the parasitic weed *Striga*, are done with bullock-drawn hoes in row crops or hand-hoeing in broadcast crops.

Scaring off birds is an important operation when the crop nears maturity.

HARVESTING Either the entire plants are cut and stacked and earheads are removed later, or the heads are cut from the standing plants. Dried heads are threshed either by cattle-trampling or with stone rollers. Grain is well dried in the sun before storage.

STORAGE The grain can be stored either in heads or after threshing; in either case, proper drying to about 10% moisture is necessary because stored grain is subject to attack by many insects. Usually stored in earthen or metallic containers, closed tightly on the top.

YIELD

Yield varies considerably depending upon cultivation practices, cv. etc. Average yield in Africa is in the range of 600-1500 kg/ha. In India, the rainfed crop gives almost equal yields, and the irrigated crop about 2500 kg/ha. In the USA, irrigated hybrid sorghum yields over 5000 kg/ha.

PESTS AND DISEASES

Striga sp., known as witchweed and belonging to the family *Scrophulariaceae*, is a semi-parasite attached to the roots of flowering plants, usually grasses. They are annual herbs with tubular corollas. Two major specie are *S. asiatica*, an erect slender herb occurring wild in Asia and Africa, and *S. hermontheca*, a more robust plant with large showy flowers that occurs mainly in Northeast and West Africa.

Seeds of both are minute and are produced in large numbers. They remain viable in dry soils for several years and germinate while in proximity with host roots. The parasitic plants draw their requirements of water and nutrients mainly from the host roots, through haustoria. Severe attack by *Striga* causes drought-like conditions to the crop. Careful weeding reduces the weed's population.

BIRDS Many species of birds attack sorghum in different parts of the world, the most serious in Africa being the small redbilled or black-faced Quelea birds, which attack in large numbers. Quelea control units are explosives, flame-throwers or poison sprays in breeding colonies or roosting sites of the birds.

INSECTS Sorghum shoot-fly, *Antherigona varia soccata*, the larvae of which burrow into the meristems of young shoots and kill the shoots, is a serious pest. Many stem borers and sorghum midge *(Contarinia sorghicola)*, are also major pests of sorghum.

DISEASES Several diseases cause serious crop losses; most important are anthracnose *(Colletotrichum graminicola)*, leaf blight *(Helminthosporium turcimum)*, downy mildew *(Sclerospora sorghi)*, and smut diseases *(Sphacelotheca* spp.).

AGROFORESTRY POTENTIAL

Being a drought-resistant, sturdy, and easy-to-manage crop that is also a staple food in the poorer parts of the world, sorghum is a very important crop for agroforestry.

MAJOR RESEARCH INSTITUTIONS AND REFERENCES

ICRISAT, Hyberabad, India.

A considerable amount of research is being carried out in many of the sorghum-growing areas; see CARIS (FAO, 1978), vol. 1 for details.

Voluminous research results are available on various aspects of sorghum. Some of the relevant compendiums are:

Curtis, D.L. 1968. Sorghum in West Africa. Field Crop Abstracts 18, 145-152.

Doggett, H. 1970. Sorghum. Longman, London.

PULSES

COWPEA

SCIENTIFIC NAME

Vigna unguiculata (L.) Walp.
syn. *V. sinensis*
Family *Leguminosae-Papilionoideae*
2n = 22, 24

COMMON NAMES

Cowpea, China pea (E)
Pois à vache, dolique de Chine (F)
Judia de vaca, judia tropical (Sp)

USES AND ECONOMIC IMPORTANCE

The dried seeds are an important pulse crop in the tropics and subtropics, providing an inexpensive source of protein, especially in Africa. They may be cooked together with vegetables, or the decorticated and dried seeds may be ground into a flour, or steamed. The young pods, stems, and leaves are used as a vegetable. Also grown as a fodder plant, and the residue of the grain crop is also used as an animal feed.

ORIGIN AND DISTRIBUTION

Cowpea is an ancient food crop, whose area of origin is uncertain, but possibly is in Asia or Africa. Now it is cultivated throughout the tropics and subtropics. The main producer is Africa, particularly the West African savanna zone, comprising Nigeria, Niger and Upper Volta. Also produced in East African countries, India, Australia, the Caribbean, southern U.S.A. and South and Central America.

PLANT CHARACTERISTICS

An annual herb showing great variation according to cv., climatic and soil conditions. Erect, trailing, climbing and bushy forms exist. Most cvs are indeterminate; life cycle varies from 60 to 240 days or more. The tap-root is stout and well developed with numerous laterals spreading in surface soil, and large nodules, often collected in groups. The stem is rounded, thin and strong, sometimes with a purple tinge. The leaves are alternate, trifoliate; the petiole is stout and grooved, 5-15 cm long; and the leaflets are large (6-15 x 4-11 cm).

Inflorescence is an axillary raceme having a long peduncle, with a few flowers crowded near the tip in alternate pairs. Flowers are conspicuously coloured; they open early in the day, close around mid-day and fall off on the same day; self-pollinated.

Pods vary greatly in size, shape, colour and texture; they are linear, crescent-shaped, or coiled, 8-80 cm long, 8-20 seeded. They are indehiscent, usually yellow when ripe. Seeds also are very variable in size, shape and colour; 2-12 mm long, globular to kidney-shaped; 100 seeds weigh 10-25 g.

Several cvs are identified and numerous species names have been given to the various forms; a great deal of confusion and disagreement exist on the classification. The catjang pea and the asparagus bean, *Vigna sesquipedalis*, widely cultivated in Asia, are also considered as forms of cowpea. Numerous high-yielding hybrid strains have also been produced.

ECOLOGY

CLIMATE Cowpea can be grown under a wide range of conditions, but it is predominantly a hot weather crop in elevations up to 1500 m. Optimum temperature range is 20-32^{o}C. It is sensitive to cold and killed by frost. Short-duration determinate types can be grown in areas of less than 600 mm annual rainfall, whereas medium- and long-duration types are grown in areas of up to 1500 mm rainfall. Excessive rainfall and high humidity are not preferred. It grows well in semi-arid climates.

SOILS Cowpea can be grown on a wide range of soils if well-drained and not subjected to waterlogging. Optimum pH is 5.5-6.5. On heavy and highly fertile soil, excessive vegetative growth and poor grain yield occur.

PHYSIOLOGY AND COMPOSITION

Short-day, day-neutral and long-day types of cowpea exist; optimal photoperiod for flower induction is 8-15 h; but seed yield, dry matter production and nodulation are all reduced in photoperiod of less than 12 h. Cowpea requires adequate sunlight for high grain yield.

The dry seeds contain approximately 11% water, 23.4% protein, 1.3% fat, 56.8% carbohydrate, 3.9% fibre and 3.6% ash.

AGRONOMY

Cowpeas are grown either in pure stands or mixed with other crops, especially cereals like sorghum, maize or millet. Propagation is by seed; the seeds are usually broadcast at the rate of 20-39 kg/ha; higher when grown for fodder.

When grown for dry seeds, they are also drilled in rows 60-100 cm apart, and 5-12.5 cm within the lines for erect types and about 30 cm for the spreading types. In hill planting, as practised in francophone Africa, the recommended hill spacings are 50x50 - 50x60 cm.

Cowpeas must be kept free from weeds during the early stages, which is usually done by hand. Cowpeas are more sensitive to herbicides than many other crops.

In peasant farming, very little manuring is done, but cowpeas respond well to 600-1000 kg/ha of a 4:8:8 NPK mixture which should be placed in bands 5 cm below the seeds, before sowing. Early cvs mature in about 3 months and green pods will be ready for picking 50 days after sowing. The pods tend to ripen unevenly. For hay making, the crop is cut when most of the pods have matured. When grown as a grain legume, time of harvesting is critical as the mature pods shatter easily and the seeds germinate quickly if there is little moisture. When harvested manually, the mature pods are picked by hand at intervals of 3-4 days; when harvested mechanically, the whole plant is cut or uprooted when the leaves begin to fall and at least two-thirds of the pods are dry. After threshing, the seed should be dried in the sun to 14% moisture content. Cowpeas are extremely susceptible to insect damage while storing.

YIELD

Yields vary considerably from as low as 150-350 kg/ha in peasant farming in Africa to over 3000 kg/ha reported in IITA, Nigeria.

With improved cvs and good management, average yields of 1000 kg/ha are obtained under field conditions.

PESTS AND DISEASES

Cowpea is susceptible to a wide range of pests and diseases. There are about 15 major pests including the bean fly *Melanagromyza vignalis*, the weevil *Piezotrachelus varius*, etc. Major diseases include the rust *Uromyces phaseoli*, bacterial canker *Xanthomonas vignicola*, fusarium wilt *Fusarium oxysporum* etc. The root-knot nematode *Meloidogyne javanica* also attacks the plant.

AGROFORESTRY POTENTIAL

The high food value of the crop, its role in peasant agriculture and diet, its short duration, the adaptability of the crop to varied soil and climatic conditions, and its leguminous nature are characteristics that add to the agroforestry potential of the crop. However, it requires full sunlight for optimum grain production. The best possibility for cowpea in agroforestry seems to be during the early years of establishment of tree species, in dense canopied plantations, and with deciduous trees.

MAJOR RESEARCH INSTITUTIONS AND REFERENCES

Considerable research has been done on cowpea in many parts of the world and most of the agricultural research institutions in the major cowpea-growing countries have strong research programmes on cowpea. The International Institute for Tropical Agriculture, Ibadan, Nigeria, has since its establishment in 1971 been involved in research on the crop.

Some of the notable literature references are:

Commonwealth Bureau of Pasture and Field Crops. Annotated Bibliography 1255 on Cowpeas *(Vigna unguiculata)* 1962-70; Berks, England.

El-Baradi, T.A. 1975. Cowpeas. Abstr. Trop. Agric. 1(12), 9-19.

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Kay, D.E. 1979. Food legumes (TPI Crop and Product Digest No. 3). Tropical Products Institute, London.

Krishnaswamy, N. 1970. Pulse crops of India-cowpea pp. 201-232. Indian Council of Agricultural Res., New Delhi.

Rachie, K.O. and L.M. Roberts. 1974. Grain legumes of the lowland tropics. Adv. Agron. 26, 1-132.

MUNG BEAN

SCIENTIFIC NAME *Vigna radiata* (L.) Wilczck
syn. *Phaseolus aureus* Roxb.,
P. radiatus L.
Family *Leguminosae - Papilionoideae*
2n = 22

COMMON NAMES Mung bean, Green gram (E)

The word 'mung bean' is also used sometimes for *urd* or black gram, *Vigna mungo.*

Ambérique, boubour (F)
Judia de mungo, frijol de oro (Sp)

USES AND ECONOMIC IMPORTANCE

Mung bean is the principal bean crop in Asia east of Pakistan, and an important crop in India. It is highly digestible and is free from the flatulence effect commonly associated with many grain legumes. *Dhal* is made from the beans, or the dried beans are boiled and eaten. Flour is also made from the beans, and the green pods are used as a vegetable. Mung beans are also grown for hay and as a fodder crop.

ORIGIN AND DISTRIBUTION

The crop originated in India or Southeast Asia; it is an important pulse crop throughout South and Southeast Asia, especially in India, Burma, Thailand, Indonesia and the Philippines. It is also grown, to a lesser extent, in East and Central Africa, the West Indies and the USA.

PLANT CHARACTERISTICS

A rapidly growing, multi-branched, somewhat hairy, deep-rooted annual, 0.5-1.0 m tall, showing considerable variation in form and adaptation. The tap-root grows very deep into the soil, and the laterals arising from it also extend obliquely downwards. The stem is multi-branched and a few cvs have a spreading habit. Leaves are trifoliate, alternate, with ovate, entire or rarely-lobed leaflets and long petioles. Flowers are yellow to greenish, occurring in clusters; normally self-pollinated. Pods are grey or brownish when mature, long and slender, with 10-20 seeds. Seeds are small, globular, often green; 100 seeds weigh 3-4 g.

Several cvs have been sorted out and high-yielding strains developed in India and to some extent in the USA. Two main types are *aureus*, yellow or golden gram, usually grown for fodder purposes, and *typica*, the green gram cultivated for grains.

A black-seeded type, *grandis*, and a brown-seeded one, *bruneus*, are also grown in India.

The crop matures in 80-120 days; longer-duration cvs have also been identified.

Black gram, or *urd*, *Vigna mungo*, is morphologically very similar to *V. radiata*.

ECOLOGY

Mung bean is grown in areas from sea-level up to 1800 m altitude where there is a warm and equable temperature of 30-35°C, and a well-distributed rainfall of 750-1000 mm per annum, of which about 400 mm is received during the growing season of the crop. Excessive rains prolong the vegetative phase. It is fairly tolerant of drought; does not tolerate frost. It can be grown on a wide range of soil types if they are well-drained and free from waterlogging. It grows on clayey soils also.

PHYSIOLOGY AND COMPOSITION

Mostly a short-day plant; but day-neutral cvs have also been identified. It is fairly tolerant of saline-alkaline conditions.

The dry seeds contain about 6-11% water, 19-24% protein, 1.2% fat, 60-65% carbohydrates, 3.3% fibre and 4% ash. Protein content as high as 31.2% has been reported.

AGRONOMY

Mung bean is usually grown as a catch crop after rice, utilizing the residual soil moisture in areas with limited rainfall; also mixed with other field crops. It is propagated by seeds; seeds retain viability for 2-3 years. They are sown broadcast or in rows 4-5 cm deep, about 50 cm apart, and 5-10 cm between plants. When sown broadcast, the seed rate is about 15 kg/ha or more. Seed rate is lower when sown in lines. The crop requires a good tilth. Mung beans respond well to phosphorus; in commercial production, 20-40 kg P_2O_5/ha (higher amounts in laterite soils) is recommended. For best results, the phosphorus fertilizer is placed in bands below the seeds at the time of sowing. The crop matures in 80-120 days, but shorter-duration cvs have also been developed. Many cvs do not ripen uniformly, so the ripe pods are usually hand-picked at 5-6 day intervals. The cv. *Pusa Baisakhi* developed recently in India matures in 65 days, and 75% of the crop can be harvested in the first picking and the remaining 10 days later. The pods, after picking, are dried in the sun prior to threshing by hand; the seeds are winnowed free of chaff and other plant parts and dried to 10% moisture content.

YIELD

Average yields vary from 300-800 kg/ha at the farmer's level. Yields up to 2400 kg/ha have been reported.

PESTS AND DISEASES

Like other legume crops, mung beans are also susceptible to many diseases and pests, some of which are common to other legume crops. The serious pests include the Asian bea fly *Ophiomyia (Melanagromyza) phaseoli*; aphids *Aphis craccivora*; the hairy caterpillar *Amsacta* spp., etc. The cowpea weevil *Callosobruchus chinensis* is the most serious pest of stored grains. Major diseases are those caused by the fungi *Cercospora* spp., *Macrophomina* spp., and *Colletotrichum* spp. The root-knot nematode *Meloidogyne* spp. also attacks the plants.

AGROFORESTRY POTENTIAL

Simlar to cowpea; mung beans are more drought resistant than cowpeas.

MAJOR RESEARCH INSTITUTIONS AND REFERENCES

Considerable research has been conducted on the crop in India, and recently in the Asian Vegetable Research and Development Center, Taiwan.

Numerous research reports on mung beans can be seen in Indian Farming and Indian J. Agric. Sci., both published by the Indian Council of Agricultural Research. Other major references are:

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PULSES

PIGEON PEA

SCIENTIFIC NAME	*Cajanus cajan* (L.) Millsp. syn. *C. indicus* Spreng. Family *Leguminosae - Papilionoideae* 2n = 22
COMMON NAMES	Pigeon pea, red gram, Congo pea, yellow dhal (E) Pois cajan (F) Guando, frijol de la India, guisante de paloma (Sp) Arhar, thuvara (India)

USES AND ECONOMIC IMPORTANCE

Young green seeds are used as a vegetable; the ripe dry seeds are boiled and eaten as a pulse; the split dried seeds known as *dhal* are a major protein source for the people of India; the dried husks and broken dhal are a good cattle feed; green plants provide an excellent fodder; and the dried stalks are used for firewood, thatching and basket making.

ORIGIN AND DISTRIBUTION

Supposed to be a native of the region between Egypt and East Africa; now it is widely spread throughout the tropics and subtropics. India is the largest producer, accounting for over 90% of the total world production.

PLANT CHARACTERISTICS

A woody, short-lived, perennial shrub, but mostly grown as an annual; 1-3 m tall, with a deep tap root and long laterals. Stems are angular, hairy and branched; branching begins 15-25 cm above ground, between 6th and 10th node. Leaves trifoliate, spirally arranged in a 2/5 phyllotaxy, inflorescences small, terminal and/or axillary racemes, 4-12 cm long. Flowering extends over several months, flowers self- or cross-compatible, about 5-40% cross pollination; rain at flowering reduces fertilization. Fruit is a flattened pod with 2-8 seeds, usually hairy; does not shatter in the field. Seeds vary in size, shape and colour; usually round or oval; 100 seeds weigh 10-15 g.

VARIETIES Two botanical varieties:

var. *flavus* - early maturing, shorter plants; green pods become light-coloured when ripe, usually 3-seeded; called *Tur* in India.

var. *bicolor* - perennial, late-maturing, large, bushy plants, hairy pods, 4-5 seeds, pods darker-coloured when mature; called *Arhar* in India.

Many cultivars (over 100) are recognized, and they are classified into early-, medium-, and late-maturing types. Numerous improved (high-yielding, short-duration, etc.) cvs have been developed.

The growth period varies considerably, from 120 to 300 days, according to the cv., location, and time of sowing. Late-maturing cvs take over 200 days, medium ones 150-200 days and short-duration types less than 150 days.

ECOLOGY

CLIMATE Wide adaptability; grows well in semi-arid regions with less than 60 cm rain per year; best growth when there is good rainfall during the first 2 months followed by a dry period during flowering and harvesting; less suitable for very wet tropics; most cultivars are sensitive to frost. The most favourable temperature range is 18-30°C. They are grown at a wide range of elevations, up to over 2000 m.

SOIL Can be grown on almost all soil types that are not very poor in lime and are not subjected to waterlogging. Optimum growth and yield are obtained in deep loam, with pH 5-7. Saline-resistant cvs have been developed.

PHYSIOLOGY AND COMPOSITION

Pigeon-pea has a deep root system, and it is somewhat sturdy and drought-resistant. Good growth in semi-arid regions, and during dry months in wetter regions. Most cultivars, notably the tall, late-maturing ones, exhibit a photoperiod effect. They are short-day plants; this affects time of maturity and height of plants according to date of sowing, and thus the ease of harvesting. For optimum yields, bright sunshine is essential.

The approximate composition of mature dry seed is: moisture 7-10%; crude protein 14-29%; carbohydrate 36-59%; fat 2%; fibre 5-9%; ash 3.8%. Pigeon peas are rich in Vitamin B, but are low in the essential aminoacids methionine and cystine.

AGRONOMY

CROPPING SYSTEM Usually grown mixed with other crops such as maize, sorghum, or millets and are left to mature on residual soil moisture after the cereal has been harvested. Also grown as a pure crop.

PROPAGATION By seed; inoculation with suitable Rhizobium strain increases the yield. Germination is hypogeal and is usually good (85-95%) with good seed; the seeds lose viability in 3-4 months after harvest in areas of high humidity.

LAND PREPARATION When grown as a mixed crop, pigeon pea also receives the same land preparation for the other crop, mainly cereals. Ridge planting recommended in areas liable to water-logging.

SOWING When grown as a pure crop, the average spacing is 30-45 cm between plants and 40-60 cm between rows; wider spacings are also adopted, especially in East Africa. Spacing also varies depending upon the growth (spreading) habit of the plant.

When grown with other crops, there is usually one row of pigeon pea for every 3-5 rows of the main crop.

Seed rate is 1.5-6 kg/ha when intercropped and 13-22 kg/ha when grown as a sole crop.

AFTERCARE Very little aftercare needed. The crop grows slowly during the early stages, i.e. in the first two months. Weed control is essential at this stage.

Very little information on nutritional and manure requirements; but studies indicate good response to phosphorus (20-80 kg P_2O_5/ha is recommended). It also requires good supply of calcium, sulphur, and zinc.

HARVESTING Unevenness of ripening makes hand-picking necessary; green pods are harvested as vegetables or ripe pods are picked as they mature. Finally when most of the leaves have dried and been shed, the plants are cut at the ground level, tied into bundles, left to dry for a few days, and then threshed.

Dhal is prepared by the dry method (drying the seeds in the sun for 3-4 days and splitting them in a mill) or by the wet method (soaking in water for 6-10 hours and then sun drying and splitting in a handmill). The dry method gives about 66% recovery of dhal and the wet method about 80%; the former fetches a better price.

YIELD

In pure stands, yields of 1500-2000 kg dry seeds per ha are obtained under good management, but average yields are 800-1200 kg/ha for pure crops and 300-900 kg/ha in mixed stands. In East Africa, yields normally average 450-650 kg/ha.

The conversion ratio from fresh green pods to dried peas is about 3.3.

PESTS AND DISEASES

The major pests of pigeon pea in India are the gram caterpillar, *Heliothis armigera (H. obsoleta)*, the red gram moth, *Exelastis atomosa*, and the pod fly, *Melanagromyza (Agromyza) obtusa*. Root-knot nematodes, mainly *Meloidogyne javanica*, also attack the crop. The stored grains are infested by pulse beetles, *Callosobruchus chinensis*. Chemical treatments are recommended against all these pests, but most of them are not very effective.

The most important disease is the soil-borne fungal wilt, caused by *Fusarium oxysporum* sp. *udum*. Crop rotations and mixed cropping are effective measures to control it. There are a few minor diseases also.

AGROFORESTRY POTENTIAL

Pigeon pea is an important species for agroforestry because of its adaptability to marginal conditions, drought-resistant and sturdy nature, food value, and amenability to mixed farming systems. Even though it needs full sunlight for optimum growth, fairly good yields can be expected under conditions of agroforestry.

MAJOR RESEARCH INSTITUTIONS AND REFERENCES

Research on various aspects of pigeon pea is undertaken in several agricultural Universities and other research centres in India and other major pigeon pea-producing countries. ICRISAT is the leading international research centre.

Numerous research reports and data are available on pigeon pea and they have been compiled by:

Kay, D.E. 1979. Crop and product digest No. 3 - food legumes. Tropical Products Institute, London.

Other major references include:

ICRISAT. 1975. International workshop on grain legumes. Hyderabad, India.

ICAR. 1970. Pulse crops of India. Indian Counc. Agric. Res; New Delhi.

Leakey, C.L.A. and J.B. Wills. (eds). 1977. Food crops of the lowland tropics. Oxford Univ. Press, Oxford.

TUBERS

ARROWROOT

SCIENTIFIC NAME	*Maranta arundinacea* L. Family *Marantaceae* 2n = 48
COMMON NAMES	Arrowroot (E) Arruruz (F) Cará maco, sagú, yuquilla (Sp)

USES AND ECONOMIC IMPORTANCE

Arrowroot starch, which is eluted from the rhizomes, has a high digestibility and is therefore a preferred food of infants and invalids. It has a high viscocity, it produces a very smooth jelly and it is used for certain types of glues. The fibrous residue, after extraction of starch, is fed to cattle. It is also supposed to have medicinal value for healing wounds. Arrowroot is one of the most important export products of St. Vincent, West Indies.

ORIGIN AND DISTRIBUTION

It is a native of South America, and is widely distributed throughout the tropics, but is of little commercial importance outside the West Indies, where St. Vincent is the main producer.

PLANT CHARACTERISTICS

It is a shallow-rooted perennial herb, 1.0-1.5 m high. Roots are adventitious and fibrous, produced at the base of the plant. Rhizomes are sympodial and distally swollen, 20-40 cm long and 2-5 cm in diameter. Stems are slender and erect; leaves distichous; lamina 10-15 x 3-10 cm, ovate to oblong; inflorescence is borne terminally and branches are subtended by deciduous bracts. Flowers are small (2 cm) and borne in pairs; cross pollination is aided by ants and other insects. Fruits are very small (about 7 mm) and seeds are two-lobed. Seeds are seldom produced in some cvs.

Two main cvs are recognized: the widely-grown 'creole' with long thin rhizomes, which develops useless thin rhizomes called "cigar roots" when grown in poor infertile soils; and the 'banana' type with shorter and thicker rhizomes, growing in clusters very near the soil surface, which are higher-yielding but have poor keeping quality.

The rhizomes mature in 10-12 months after planting.

ECOLOGY

Arrowroot prefers tropical lowland conditions (up to 1000 m altitude) with 1500-2000 mm of well-distributed rainfall; it does not tolerate waterlogging. Fertile and friable sandy loams are preferred for better tuber development and easy harvesting.

PHYSIOLOGY AND COMPOSITION

Very little is known about the physiology of the crop, but it prefers shade to some extent, especially when grown on light soils.

The starch grains are 15-70 µ in length and are oval in shape. Fresh rhizomes contain 69-72% water, 1.0-2.2% protein, and 19-22% starch.

Arrowroot starch retains its high viscocity on heating, unlike that of cassava and sago, whose viscocity falls when temperature increases.

AGRONOMY

Arrowroot, on a commercial scale, is grown as a sole crop; but it can also be intercropped with other crops and in light shade. The crop is propagated by selected 2-4 node-long tips of rhizomes known as "bits"; about 3500 kg are required to plant one hectare. Portions of rhizomes remaining in the soil after harvesting provide part of the ratoon crop. After thorough ploughing and forking, the bits are planted 5-7.5 cm deep and about 30 cm apart. The crop is hand-weeded 3-4 times. Fertilizers are applied before flowering begins at the rate of 70-130 kg N, 50 kg P_2O_5 and 200 kg K_2O per hectare. The crop matures in 10-12 months, as indicated by yellowing and wilting of the leaves. Usually harvesting is by hand. Successive cropping on the same land is allowed for 5-6 years. Yield varies considerably from 10-35 t rhizomes per ha.

The rhizomes contain the maximum amount of starch when the crop is 12 months old, but then they are more fibrous and the starch is difficult to extract. Cleaned and washed rhizomes are rasped, crushed, and mixed with water and the pulp is passed through a series of sieves. The starch settles in troughs and the fibrous tissue or bittie is separated. The starch is then mixed with more water and resettled (which may be done by centrifuging), and dried in the air or in mechanical driers. Chlorination of water used for processing helps to prevent bacterial fermentation. About 16-18% starch is recovered from rhizomes. It is graded on the basis of colour (white is preferred), cleanliness, freedom from specks, pH, viscosity etc. 'Banana' cv. has higher moisture and protein in its rhizomes and less fibre and starch than 'creole', but the starch can be extracted more easily from the former. However, 'banana' rhizomes must be processed within 48 hours after harvesting, whereas 'creole' rhizomes can remain before processing for several (up to seven) days.

YIELD

Yield varies considerably from 10-35 t rhizomes per hectare.

PESTS AND DISEASES

Under high rainfall and poor drainage conditions, a burning disease caused by *Rosellinia bunodes* occurs. In poor and infertile soils, long, thin rhizomes known as cigar roots are produced, which are useless.

AGROFORESTRY POTENTIAL

Arrowroot requires moderate shade and is a species of good potential for agroforestry in tropical lowlands.

RESEARCH INSTITUTIONS AND REFERENCES

Very little research has been done; breeding work is difficult owing to poor seed-setting and germination. The Field Crops Division, Department of Agriculture, Thailand is doing some agronomic work on the crop.

Holttum, R.E. 1951. The Marantaceae of Malaya. Gardens' Bull., Singapore. 13, 254-296.

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Tomlinson, P.B. 1961. Morphological and anatomical characteristics of the Marantaceae. J. Linn. Soc. (Bot.), 58, 55-78.

CASSAVA

SCIENTIFIC NAME	*Manihot esculenta* Crantz
	syn. *M. utilissima* Pohl
	Family *Euphorbiaceae*
	2n = 36
COMMON NAMES	Cassava, manioc, tapioca (E)
	Manioc (F)
	Mandioca, yuca (Sp)

USES AND ECONOMIC IMPORTANCE

Cassava root tubers are an important food and carbohydrate source in many parts of the lowland tropics, where cassava cultivation has been encouraged as a famine reserve. Starch is also prepared from the tubers. Leaves are used as a pot-herb, and dried leaves as a fodder for cattle. Beer and other alcoholic drinks are also made from cassava.

ORIGIN AND DISTRIBUTION

Believed to be a native of north-eastern Brazil or Central America (Mexico and parts of Guatemala). Now, cultivated in the area between 25^{o}N and 25^{o}S. Africa has more cassava than all the rest of the world.

PLANT CHARACTERISTICS

A short-lived shrub, 1-5 m in height, with latex in all its parts.

Tubers develop as swellings on adventitious roots a short distance from the stem by a process of secondary thickening. There are usually 5-10 tubers per plant, cylindrical or tapering, 15-100 cm long, 3-15 cm in diameter. The edible portion is the core or the pith covered by an outer skin (periderm) and a thin rind or cortex; it is rich in starch and usually white in colour. Old tubers become lignified. The stem varies greatly in length, branching habits, etc.

Leaves are spirally arranged in a 2/5 phyllotaxy; petiole 5-30 cm long, lamina deeply divided with 3-9 lobes.

Flowers are borne in axillary racemes near ends of branches; flowers are unisexual; male and female flowers occur in the same inflorescence and are cross-pollinated, entomophilous; the fruit is a globose capsule, 1-5 cm long, 3-seeded. Under natural conditions, germination is protracted and erratic.

Usually plants are harvested 6-11 months after planting, but long-season cultivars are left for longer periods.

Many cultivars or clones are known. Generally they are divided into sweet cassavas, with low HCN content (which are short-season cvs), and bitter cassavas, which have more firm and yellow flesh than the sweet cassavas and tend to be long-season cvs.

ECOLOGY

CLIMATE Cassava is essentially a tropical lowland crop, but it can be grown up to 1500 m above sea level. It cannot withstand frost or cold. It is grown in areas with 500 to 4000 mm rains per annum; it can withstand drought (except at planting), but not waterlogging.

SOIL Generally cassava prefers a loose and friable soil, but it can be grown on diverse soil types that are not too shallow or stony. It will produce an economic crop on relatively poor soils that are unsuitable for other crops. However, heavy clays and saline and swampy soils are unsuitable.

PHYSIOLOGY AND COMPOSITION

Cassava can produce a reasonably good crop in partially shady conditions, but too much shade results in lanky growth. Highly fertile soils may result in excessive vegetative growth at the expense of tuber and starch formation.

Cassava contains the toxic principle, hydrocyanic acid (HCN) in the proportion of 10-370 mg/kg of fresh tuber. In sweet cassava, HCN is confined to the rind, whereas in bitter cassava it is more widely distributed, and must be destroyed by boiling, roasting, fermentation, etc. The average composition of peeled cassava tubers is: moisture 62-65%; carbohydrate 32-35%; protein 0.7-2.6%; fat 0.2-0.5%; fibre 0.8-1.3%.

AGRONOMY

Cassava is grown either as a pure crop or is interplanted with homestead horticultural crops. Propagation is by stem cuttings, 20-30 cm long, taken from the middle of mature stems. Usually land is prepared by a deep ploughing which facilitates maximum tuber development. The crop may be planted on the flat, on ridges, or on mounds; the usual spacing is 1 m x 1 m; may be planted at wider spacings also; sometimes 2-3 cuttings are planted together. Germination takes place within the first week, and usually it is about 95%. Adequate moisture is necessary at the time of planting, but after establishment the plant can withstand drought during which it will shed its leaves; the leaves reappear after rains. Weeding is done during the early stages. Earthing-up the soil around the stems 2-3 months after planting favours tuber development and removes weeds.

Cassava is seldom manured in marginal areas and under suboptimal conditions of management. But optimal manuring can give good yields: 100 kg K_2O and 50 kg N/ha, depending upon soil fertility, can give yields of over 30 t/ha. Organic manures are applied in the planting pits at the time of planting and fertilizers are applied after the crop's establishment at the time of earthing-up.

Maturity is indicated by yellowing and shedding of leaves. Harvesting is done by pulling out the whole plant, for facilitating which the above-ground portions are sometimes removed before pulling out, and/or the soil at the base is wetted or loosened. Tubers cannot be kept for more than 48 hours after harvesting; therefore, harvesting is done as the demand or marketability is assured.

Sweet cassava may be eaten raw after peeling; in bitter cassava, HCN is destroyed by washing and cooking. Fresh tubers do not keep long, but may be sliced and dried in the sun with or without parboiling, the latter enhancing keeping quality. Starch is prepared by grating or grinding washed peeled tubers and squeezing in repeated changes of water.

YIELD

Yield varies considerably depending upon cv., soil, climate, management, age at harvesting etc.; yields from small holdings average 5-15 t/ha. Intensive cultivation can give yields over 30 t/ha.

PESTS AND DISEASES

Various pests such as leaf-eating caterpillars, stem borers, spider mite, scale insects, etc. can cause considerable damage. The nematodes *Meloidogyne* and *Pratylenchus* also are serious, especially in the Ivory Coast and Nigeria.

Cassava mosaic virus, which causes mosaic and curling of leaves, is the most serious disease. It is transmitted by white flies, *Bemisia* spp. Leaf spot caused by the fungus *Cercospora cassavae*, bacterial wilt, *Xanthomonas manihotis*, and others are minor diseases.

AGROFORESTRY POTENTIAL

Cassava can be grown in areas where other crops do not grow well, under partial shade, and with little labour and care; it can be kept in the ground until required or for times of food shortages; and the virus disease is its only serious threat. Thus, cassava has excellent agroforestry potential.

MAJOR RESEARCH INSTITUTIONS AND REFERENCES

There are several institutions doing research on cassava. For example, Brazil, Fiji, Indonesia, India, Nigeria, Zambia, Zaire, etc. have national institutions which carry out research on various aspects of cassava production, protection and processing. CIAT (Centro Internacional de Agricultura Tropical) at Cali, Columbia, and IITA (International Institute of Tropical Agriculture) at Ibadan, Nigeria are the major international research centres.

Major references include:

CIAT. 1975. 2000 Abstracts on cassava. Centro Internacional de Agricultura Tropical, Cali, Columbia.

Kay, D.E. 1973. Cassava. *In* Root crops. pp. 24-39. The crop and product digest No. 2, Tropical Products Institute, London.

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Weber, E.; B. Nestel and M. Campbell. 1979. Intercropping with cassava. IDRC 142e: International Development Research Centre, Ottawa.

Fig. 14a. Cassava under coconuts (Photo credit: Central Plantation Crops Research Institute, Kasaragod, Kerala, India).

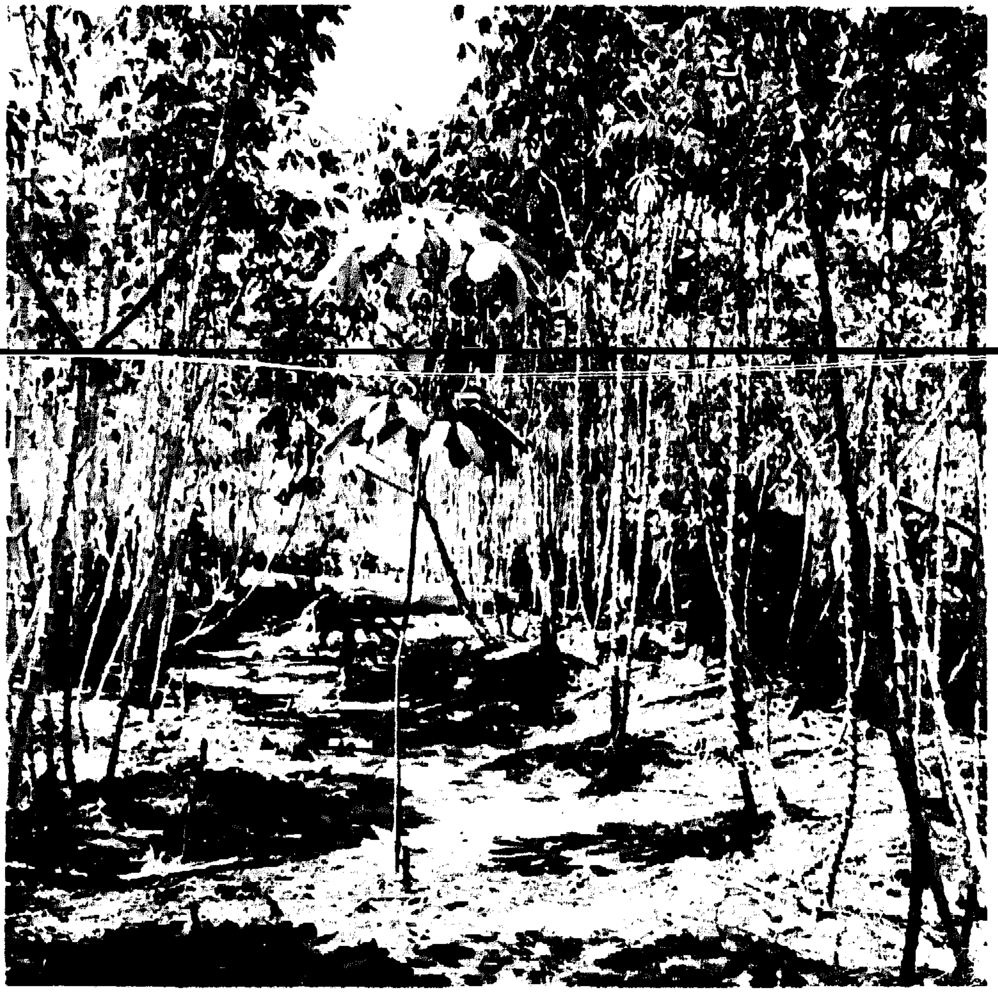

Fig. 14b. Six month-old rubber tree intercropped with cassava (Photo credit: Rubber Research Institute of Malaysia).

TUBERS

POTATO

SCIENTIFIC NAME

Solanum tuberosum L.
Family *Solanaceqe*
2n = 48

COMMON NAMES

Potato, Irish potato	(E)
Pommes de terre	(F)
Patatas	(Sp)

USES AND ECONOMIC IMPORTANCE

Potato is the major starchy root crop of temperate countries, and an important crop in some tropical highlands. It is the most important vegetable in the world today. Potatoes are eaten boiled, roasted, baked or fried and are processed into a wide range of products. Potatoes have subsidiary uses as stock feed and for preparation of large-grained starch, flour, and alcohol.

ORIGIN AND DISTRIBUTION

Potato originated in South America in the Andes between 10°N and 20°S latitudes at about 2000 m, primarily around lake Titicaca in Bolivia. Today the largest producer is Europe (accounting for 90% of world's potato crop), but it is grown more universally than any other crop, except in the tropical lowlands.

PLANT CHARACTERISTICS

A herbaceous branched annual, sometimes with a perennial habit because of its ability to reproduce from tubers, 0.3-1.0 m high. The root system consists of fine, fibrous, adventitious roots and swollen stem tubers. The stem is erect in early stages, but later becomes spreading or prostrate. Leaves are alternate and compound, irregularly odd-pinnate with petioled leaflets between the main pinnae. Many cvs produce a determinate flower cluster, consisting of white, red or purple flowers with five-lobed corolla. Mostly self-pollinated, the fruit is a small spherical inedible berry. The tubers are modified thickened underground stems, their size, shape and colour varying according to the cv. Considerable progress has been achieved in improving potatoes, and several cvs suited to specific growing conditions and with specific characteristics have been produced. Maturity periods vary considerably; early cultivars mature in 3-3½ months, medium in 4-5 months, and late cvs in up to 7 months, depending upon environmental conditions. In the tropics, the crop usually matures in 3-4 months.

ECOLOGY

CLIMATE The potato has specific temperature requirements. Optimum temperatures for maximum yield are in the range of 15-18°C throughout the growing season. Tuberization is retarded when soil temperature rises above 20°C. Day temperatures above 21°C and night temperatures above 10-14°C have adverse effects. However, the crop does not withstand frost. Rainfall of 50-75 cm, evenly distributed throughout the growing period, is optimal. The crop does not tolerate drought. Under humid conditions, the control of late blight disease is difficult. In the tropics the crop is grown in altitudes above 1500 m; the essential requirement is a marked cool season.

SOIL For optimum yields, the potato prefers a deep well-drained or sandy loam, with a pH of 5.5-6.0 and well-supplied with plant nutrients. Heavy clays and poorly-drained soils are unsuitable.

PHYSIOLOGY AND COMPOSITION

Short-day and long-day cvs are available; South American cvs produce reasonable yields with a day length of 12-13 h, whereas the early cultivars grown in temperate regions require 15-16 h-long days. Long-day cvs are unsuitable for the tropics. The crop grows under reduced light intensity, but for better yields the light intensity should be higher.

Approximate composition is: water 63-87%; protein 0.7-4.5%; carbohydrate 13-30%; fibre 0.2-3.5%. Potato starch contains 25% amylose and 73% amylopectin. Potatoes are also an important source of protein, iron, riboflavin and ascorbic acid in potato-rich diets.

AGRONOMY

In commercial cultivation, potatoes are grown as a sole crop, but being vegetables, they are also grown mixed with other crops on the homestead.

Propagation is by whole or, sometimes, cut tubers, known as "seed", weighing about 50 g. Good, healthy planting material is essential. Potato tubers have a dormancy of about 8 weeks, which can be broken by keeping the tubers in 20-30°C for 30-40 days, or by chemical treatment. Tubers are sprouted before sowing, by the process known as chitting which involves spreading the tubers one or two layers thick in diffuse light at a temperature of more than 10°C. Seed potatoes are treated with various fungicides before sowing.

Planting is done on ridges that are about 75 cm apart. When planted on the flat ground, soil is heaped around the stem during weeding, which facilitates tuberization. Usually, the seed is planted 10 cm deep, at a spacing of 20-30 cm along the rows. Seed rate depends upon spacing, type of seed material (whole or cut tubers) etc., but usually it is 1200-1800 kg/ha. The plants grow and cover the ground quickly so that weeding may not be necessary about six weeks after sowing. The crop is irrigated about once a week in dry weather.

Potatoes respond well to manures and fertilizers. They are particularly heavy feeders of potassium. Fertilizer requirements vary considerably according to cultivar, soil type, and climatic conditions. General recommendations are in the range of 35-70 kg N, 50-100 kg P_2O_5 and 80-150 kg K_2O per hectare. Potassium sulphate, rather than potassium chloride is used as the source. Maturity is indicated by yellowing and drying of the foliage. In commercial production, the foliage is killed by mechanical and/or chemical methods 2-3 weeks before harvesting, during which time the skin of the tuber hardens so that there will be less damage while transporting. Harvesting is done mechanically in commercial production, but can also be done manually, by digging.

The tubers can be stored successfully for periods up to 8 months at temperatures of 3-4°C. Prolonged storage favours the accumulation of excessive quantities of sugars. Chemicals such as maleic hydrazide, iso-propyl phenylcarbamate etc. are used to suppress sprouting in storage.

YIELD

In the tropics, yields are usually lower, in the range of 6-10 t/ha. In temperate regions with longer growth periods, yields of over 40 t/ha can be obtained with efficient farming methods.

PESTS AND DISEASES

Different species of aphids (most important: potato aphid, *Macrosiphum euphorbiae)* and flee beetles (most important: potato flea beetle, *Epitrix cucumeris* and tuber flea beetle, *E. tuberis)* attack the crop.

But the most widespread and serious malady is the fungal disease called late blight, caused by *Phytophthora infestans.* Early blight, *Alternaria solani* is another widespread disease. In addition, there are several other fungal, bacterial, and viral diseases and nutritional and physiological disorders.

AGROFORESTRY POTENTIAL

The potato can be profitably cultivated as an agroforestry species in tropical mountain ecosystems and during the cooler season in the subtropics.

MAJOR RESEARCH INSTITUTIONS AND REFERENCES

There are several research institutes on the potato in different potato-growing countries. The International Potato Centre in Lima, Peru, is the major international institute. Publications from these institutes, the proceedings of the Symposia on Tropical Root and Tuber Crops, the American Potato Journal, and the common journals of agricultural sciences publish the research results. Major books on potato are:

Burton, W.G. (1966) The potato. 2nd ed. H. Veenman and Zonen, Wageningen.

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TUBERS

SWEET POTATO

SCIENTIFIC NAME	*Ipomoea batatas* (L.) Lam. Family *Convolvulaceae* 2n = 90
COMMON NAMES	Sweet potato (E) Patates douces (F) Batatas, camotes (Sp)

USES AND ECONOMIC IMPORTANCE

The edible tubers of sweet potato are an important source of food throughout the tropics. The tubers are eaten boiled or baked, may be candied with syrup; also used for canning, dehydrating, and as a source of starch, glucose and alcohol. Sweet potato vines are an important animal feed, especially during the dry season. The tender tops and leaves are used as a pot-herb in Africa and Southeast Asia.

ORIGIN AND DISTRIBUTION

Originated in tropical America. Now it is cultivated throughout the tropics, the largest area being in Africa. Outside the tropics, the major producers are Japan, China, the U.S.A. and New Zealand.

PLANT CHARACTERISTICS

Sweet potato is a perennial herb although it is treated as an annual crop. It has a vine-like, trailing, sometimes twining stem, 3-10 mm in diameter and 1-5 m long, with latex in all parts. Internodes are 2-10 cm long. The stem seldom rises more than 50 cm from the ground. An extensive, superficial, fibrous, adventitious root system is produced from the nodes of the planting material; stems in contact with the soil also produce roots at the nodes. Tubers, about 10 per plant, develop in the top 25 cm of soil by secondary thickening of some adventitious roots, mostly from the original cutting, but also from the trailing vines. Tubers are smooth or ridged, globular; colour of the periderm and flesh varies depending upon the cultivar.

Fresh sweet potatoes contain 70% water, 1.5-2% protein, 0.2% fat, 27% carbohydrate and 1% fibre. Sugar content varies from 3 to 6%. Yellow- and orange-fleshed cvs are rich in vitamin A. Leaves contain 3.2% protein and 8.5% carbohydrate.

AGRONOMY

CROPPING SYSTEM Usually planted as a pure crop, but in rotation with other crops. In freshly-cleared areas, sweet potato is the first crop, as it covers the ground quickly and smothers the weeds. It is also cultivated in steep slopes where it checks erosion better than most other crops, on small plots near the homestead, along roadsides where tall crops are prohibited by law and in valley bottoms. On homesteads, they are grown as intercrops under the perennial (tree) crops.

PROPAGATION Invariably propagated by apical stem cuttings from mature plants. Length of the cuttings varies from 30-90 cm depending upon local customs. Sometimes partially wilted cuttings are preferred. A limited stock of planting material can be multiplied in a nursery, which will be ready in 4-6 weeks. In temperate countries, sprouts or slips obtained by planting medium-sized tubers close together in nursery beds are used for planting. In breeding work, propagation by seed is adopted, for which the seeds are treated with concentrated sulphuric acid for 45 minutes. Germination is, however, very irregular. It is also possible to propagate by single leaf cuttings, but it is not practised commercially.

LAND PREPARATION Sweet potato is usually planted on ridges or mounds. Ridges are about 45 cm high, usually 1 m apart and cuttings planted 30 cm apart on either side. Mounds are about 75 cm high, about 90 cm apart and 3-4 cuttings planted per mound. If the soil is sufficiently friable and well-drained, sweet potato is planted in beds.

PLANTING, PLANT POPULATION Cuttings are planted at any angle with half of their length from the cut end buried in the soil. Long cuttings are planted flat; occasionally only the middle part of the cuttings is buried, both ends being exposed.

Leaves are spirally arranged with 2/5 phyllotaxy, very variable even on the same plant. Lamina is mostly ovate in outline, entire to deeply lobed.

Most cvs flower freely in the tropics; flowers are axillary, solitary or cymose; the peduncle is 3-15 cm long; calyx deeply 5-lobed; corolla funnel-shaped, 3-5 cm long. Flowers open before dawn and close and wilt the same morning about 10 o'clock; the time of closure will be delayed in cool and cloudy weather. Natural cross-pollination occurs through bees and other insects. Almost all cvs are self-sterile and some are cross-incompatible.

The fruit is a glabrous or hirsute dehiscent capsule, 5-8 mm in diameter, containing up to 4 seeds.

The first tubers can be harvested in about 4 months, but the duration of the crop depends upon climate, soil, cultivar, etc. They can be left on the ground and harvested according to demand.

There are many cvs with considerable variability among different cvs. Many high-yielding hybrids have also been evolved.

ECOLOGY

CLIMATE Grows well in places having a 4-6 month growing period with an average temperature of 24°C, and 75-125 cm of well-distributed annual rainfall.

It is grown from 40°N to 32°S; on the equator, it is grown from sea level to about 2,500 m. It does not withstand prolonged drought; in East Africa, sweet potatoes are often planted along swamp margins during the dry season in order to maintain adequate planting material and provide out-of-season tubers.

SOILS The crop is grown on a wide variety of soils, but a well-drained sandy loam with clay subsoil is ideal. Better yields are obtained in fertile soils rich in organic matter.

PHYSIOLOGY AND COMPOSITION

Sweet potato is a short-day plant; flowering takes place at a photoperiod of 11 hours or less. No flowering occurs at all at 13½ hours daylight, so little flowering occurs in areas above 30°N and S. The crop does not withstand waterlogging.

A plant population within the range of 20,000-40,000 per hectare seems to have little effect on yield.

PLANT NUTRITION, MANURING The crop responds well to organic manures. Too much nitrogen encourages excessive growth of vines at the cost of tubers. An NPK mixture of 6:9:15 at the rate of 500-1,000 kg/ha is recommended for good yields.

AFTERCARE Usually very little aftercare is necessary; weeding is not a great problem because the crop covers the ground quickly. However, during the first month or two after planting, weeding is done once or twice. The vines are sometimes turned back from time to time to prevent rooting at the nodes in order to ensure a more uniform crop.

HARVESTING Usually harvested as required because fresh tubers do not keep for more than a few days. The time taken to maturity is 3-6 months depending on the cv.; maturity can be judged by the leaves turning yellow and dropping, or by cutting a tuber, the sap of which, if mature, will dry up rapidly. A sharpened stick or a small hand tool can be used for harvesting.

PROCESSING Fresh tubers, which do not keep for more than a few days, are usually eaten baked or boiled. In temperate countries, the tubers are cured before storage by keeping them at about 30°C and 85-90% relative humidity for 2-3 weeks and then gradually reducing the temperature to 10-12°C and relative humidity to 80%. The tubers can be stored for longer if they are sliced and dried, but it is rarely practised.

YIELD

Yield varies considerably from as low as 3 to as high as 50 t/ha depending upon the cv., management practices, etc. A yield of 15-20 t/ha is considered satisfactory.

PESTS AND DISEASES

Sweet potato weevil, *Cylas formicarius* is the major pest; the larvae tunnel into the vines and tubers, causing discolouration and bitterness. Crop rotation and dipping the planting material in insecticidal solution are the recommended control measures.

Sweet potato virus, transmitted by the white fly *Bemisia* spp., causes stunting, excessive branching, yellowing of the vines and hardness of the tubers.

AGROFORESTRY POTENTIAL

Sweet potato is a good species for agroforestry because of its wide adaptability, tolerance to partial shade, ease of cultivation and management, facility for staggered harvesting, etc.

MAJOR RESEARCH INSTITUTIONS AND REFERENCES

Central Research Institute for Agriculture, Padang, Indonesia.
Central Tuber Crops Research Institute, Trivandrum, India.

Also several research units in many institutions in different parts of the tropics.

Important publications include:

Edmond, J.B. and G.R. Ammerman. 1971. Sweet potatoes: production, processing and marketing. Avi Westport, Connecticut.

Kay, D.E. 1973. Sweet potato pp. 114-159. *In* Root crops. Crop and product digest No. 2; Tropical Products Institute, London.

Proceedings of the International Symposia on Tropical Root and Tuber Crops.

Steinbauer, C.E. and L.J. Kushman. 1971. Sweet potato culture and diseases. US Dep. Agric.; Agric. Handbook No. 338.

TUBERS

TARO

SCIENTIFIC AND COMMON NAMES

Many members of plants belonging to the botanical family *Araceae* produce edible tubers and rhizomes known as taro, dasheen, cocoyam, etc. The more important are:

Colocasia esculenta (L.) Schott var. *esculenta*
Colocasia esculenta (L.) Schott var. *antiquorum*
Xanthosoma sagittifolium (L.) Schott, and
Amorphophallus campanulatus (Roxb) Blume (elephant yam).

Taro, colocase (F)
Taro, colocasia (Sp)

USES AND ECONOMIC IMPORTANCE

Taro is grown as a root crop throughout the humid tropics, especially in Southeast Asia (mostly *C. esculenta)* and the West Indies (mostly *C. antiquorum* and *Xanthosoma).* The corms and rhizomes are roasted, baked or boiled and eaten, sometimes as a substitute for potatoes. The young leaves and stem are used as a vegetable and sometimes for soup. Elephant yam is cultivated in South India and Southeast Asian countries.

ORIGIN AND DISTRIBUTION

Colocasia is a native of Southeast Asia and *Xanthosoma* is of tropical American origin. Both are widely distributed in the humid parts of the tropics and of many subtropical countries.

PLANT CHARACTERISTICS

Colocasia is a 1-2 m tall herb; has an underground starchy corm which produces a whorl of large leaves with long erect petioles. *C. esculenta* corms are usually cylindrical, about 15 cm in diameter and 30 cm long, with short internodes and axillary buds and few small side-tubers. The root system is fibrous and superficial. Petioles are stout at the base and up to 1 m long. The lamina is broad and oblong-ovate. Inflorescence is a spadix with a stout peduncle, cylindrical in shape, with female flowers to the base. Many cvs do not flower.

C. antiquorum produces a large number of tubers, clustering around the main central corm, and some cvs are much shorter than *C. esculenta*. The tubers are free from acridity and, when cooked, have a pleasant flavour.

Xanthosoma is more robust than *Colocasia* and has a shorter stem and larger-stalked leaves. About 10 lateral tubers are produced, each 15-25 cm long and flask-shaped with a broader apex.

Colocasias and Xanthosoma show considerable variations with respect to size and shape of leaves and tubers and other plant characteristics; several cultivars are grown.

ECOLOGY

Taro prefers a warm humid climate with about 2500 mm of annual rainfall and wet, fertile soils. In dry regions and loose soils, the growth is poor unless supplemented with irrigation and manures. It grows in swampy areas and in tropical rain-forests.

PHYSIOLOGY AND COMPOSITION

Not much is known about the physiology of this crop. But it prefers light shade, tolerates swampy conditions and waterlogging which makes it an ideal sp cies for agroforestry in tropical lowland forests and mangrove areas.

The approximate composition of taro is: water 60-80%; protein 1.5-3.5%; fat 0.2-0.4%; carbohydrate 15-25%; fibre 0.6-1.2% and ash 0.6-1 2%. It contains appreciable quantities of vitamins B and C.

AGRONOMY

CROPPING SYSTEM Usually grown in wetter areas either in pure stands, mixed with other annual garden land crops, or as understorey crops in tree crop areas. Also grown as a nurse crop for cacao.

PROPAGATION Taro is propagated vegetatively by planting tops of the main corm or rhizome, or by small side tubers or suckers. Elephant yam is propagated by cuttings of the corms, each bearing one sound bud and weighing 300-500 g.

SOWING Usual spacing for taro is 60-90 cm and for elephant yam 90-120 cm. Taro is sometimes planted on ridges 1 m apart or on raised beds as in the case of ginger and turmeric. Planting depth is about 10 cm for taro and 15 cm for elephant yam.

AFTERCARE Taro and elephant yam respond well to manuring. It is a usual practice to apply a good amount of organic matter (1-2 kg per plant) in the planting pit, and to mulch with organic materials after planting. The general fertilizer recommendation in Hawaii is about 100 kg N, 200 kg P and 100 kg K per ha, whereas in India the recommendation is for 80:60:80 kg N, P_2O_5 and K_2O per ha. Nitrogen, and sometimes K, are applied in equal quantities as basal dressing and top dressing. One or two weedings (hand hoeing) and earthings up are also done.

HARVESTING The crop matures in 7-9 months when the leaves begin to turn yellow. Harvesting is done by digging; staggered harvesting is possible.

The tubers can be stored under dry and well-ventilated conditions for several weeks. Sometimes they are stored under shade in dry sand or in rice husks or similar light dry materials.

YIELD

Average yield varies from 15-20 tons of fresh tuber per hectare; but yields are lower in dry areas and under poor management. Much higher yields are possible under better management.

PESTS AND DISEASES

Leaf hopper, leaf blight caused by *Phytophthora colocasiae*, attacks by saprophytic fungi such as *Pythium*, and root knot nematode, *Meloidogyne* spp., are the major enemies.

AGROFORESTRY POTENTIAL

The different species of taro are well adapted to agroforestry conditions of low light, marginal lands, etc. Moreover, they tolerate waterlogging and swampy areas.

MAJOR RESEARCH INSTITUTIONS AND REFERENCES

Agricultural Research Station, Kade, Ghana.

Central Tuber Crops Research Institute, Trivandrum, India.

Dobuilevu Research Station, Nausori, Fiji.

Campbell, J.S. and H.J. Gooding. 1962. Recent developments in the production of food crops in Trinidad. Trop. Agriculture, Trin. 39, 261-270.

Coursey, D.G. 1968. The edible aroids. World Crops 20(4), 25-30.

Kay, D.E. 1973. *In* Root crops. TPI Crop and Product Digest No. 2. Tropical Products Institute, London.

Plucknett, D.L., R.S. de la Peña and R. Obrero. 1970. Taro *(Colocasia esculenta)*. Field Crop Abstr. 23(4), 413-426.

Fig. 15. Taro *(Xanthosoma* spp.) (left) and arrowroot (right) (Photo credit: Centre d'Etude de l'Azote, Zurich).

Fig. 16. Home garden with sugarcane, bananas, groundnut, cassava and taro in Columbia (Photo credit: Royal Tropical Institute, Amsterdam).

Fig. 17a. Yams under coconut palms (Photo credit: CPCRI, Kasaragod, Kerala, India).
left: Lesser yam, *Dioscorea esculenta*.
right: Greater yam, *Dioscorea alata*.

Fig. 17b. Yams supported by live, pruned *Leucaena leucocephala* (Photo credit: G.F. Wilson, IITA, Nigeria).

TUBERS

YAM

SCIENTIFIC NAME	*Dioscorea* spp.	
	Family *Dioscoreaceae*	
COMMON NAMES	Yams	(E)
(There are different species; see below)		
	Igname	(F)
	Ñame, yame	(Sp)

USES AND ECONOMIC IMPORTANCE

Edible yams provide the staple carbohydrate food in the yam zone of West Africa (between central Ivory Coast and the Cameroon mountains, including Ghana, Tobago, Dahomey and Nigeria). They are also grown in the Caribbean and in South and Southeast Asia (India, Indonesia, Oceania) and to some extent in other tropical countries. They are usually consumed after peeling and boiling, roasting whole or small tubers, or partial boiling. Also eaten as fufu, a gelatinous dough prepared either with yam alone or with cassava, banana, etc. by pounding in a wooden mortar after peeling boiled cut pieces. Yams are also used as food in times of scarcity and famine. Some species are used in the manufacture of oral contraceptives and sex hormones.

ORIGIN AND DISTRIBUTION

(See the previous and the next sections).

PLANT CHARACTERISTICS

The edible portions of the Dioscorea yams are rhizomes which are enlarged annual storage organs. The planting material produces twining shoots and then shrivels away: afterwards, tubers develop and enlarge. The shoots dry away during the dry season, but the tubers remain dormant and produce new shoots when the rains set in. Aerial axillary bulbils are formed in some species.

The genus Dioscorea contains about 600 species, of which the important ones cultivated for their edible tubers are:

D. alata: water yam, greater yam
D. esculenta: lesser yam, Chinese yam
D. rotundata: yellow yam, Guinea yam, and
D. trifida: cush-cush yam.

D. alata is a native of Asia, the highest yielding of the cultivated yams, and the preferred species in most parts of the world. The stems are square, spineless, and twining to the right; leaves opposite and ovate 10-30 x 5-20 cm; tubers usually single, large (5-10 kg) and cylindrical (but shape of tubers varies considerably). Usual growing period is 8-10 months, with 2-3 months dormancy before sprouting.

D. cayenensis is a native of and grown widely in West Africa. It is hardier and higher-yielding than *D. rotundata*. The flesh has a pale yellow colour; the tubers have a short dormancy and do not store well. The stem is long (to 10-12 m), cylindrical, twining to the right, spiny; the leaves are opposite or alternate, 8-10 x 3-6 cm.

D. esculenta is a native of Southeast Asia, and is not widely grown outside Asia and the Pacific. A cluster of 15-20 small cylindrical tubers of 15-20 cm length are produced near the soil surface; the tubers have a thin brownish skin and a short dormancy; the flesh is white, with few fibres, soft in texture, and of good palatability and slightly sweet taste. Stems are cylindrical, spiny, twining to the left; leaves are alternate, simple, rounded and about 12 cm on the longest plane.

D. rotundata is a native of West Africa, where it is the most important cultivated species. Grows well in places with longer dry periods, being well-adapted to the savanna regions of West Africa. Tubers are cylindrical, have smooth brown skins and white flesh; usually weigh 2-5 kg per tuber; and have a dormancy that facilitates their storage. Stems are cylindrical, up to 10-12 cm long, twining to the right, usually spiny; the leaves are usually opposite, simple, 10-12 x 6-8 cm.

D. trifida is a native of South America and is cultivated along with *D. alata* throughout the Caribbean area. Tubers are small, 15-20 cm long, and produced in groups; flesh is white, yellow or pink; stems are quandrangular and twining to the right; leaves are large, palmately 3-5-lobed, 15-25 cm long and broad.

ECOLOGY

CLIMATE Yams are tropical crops that grow well in the temperature range of 20-30°C. They require at least 1000 mm of rainfall per annum, preferably more. *D. cayenensis* cannot tolerate more than 2-3 months of rain-free period. *D. alata* and *D. rotundata* require about 8 months to complete their life cycle; the critical period when they cannot tolerate drought is about 3-5 months of growth when the food reserves of the sett (planting material) are exhausted by the rapidly-growing shoots before new tubers have been formed. If the drought period extends, tuber size and yield are reduced.

SOIL Yams require loose and friable soils of moderate fertility that are not subjected to waterlogging. Usually they are grown as the first crop after clearing the "bush fallow" in shifting cultivation.

PHYSIOLOGY AND COMPOSITION

Since the stems climb by twining, it is a general practice to trail the vines to trees; the vines reach the top of the tree canopy and the leaves expose themselves to sunlight. Thus yams can be grown under trees.

The effect of photoperiod on yams has not been fully understood; day lengths greater than 12 h appear to favour development of the vine and short days (10-11 h daylight) favour tuber growth.

The approximate composition of edible yam tubers (90-95% of the whole tuber, the rest being skin which is lost by peeling) is: water 65-75%, protein 1-2.5%, carbohydrates 15-25%, fibre 0.5-1.5% and ash 0.7-2.0%. They contain 8-10 mg/100 g of ascorbic acid, which is not lost in cooking.

AGRONOMY

CROPPING SYSTEM Usually grown on small holdings in areas of traditional and subsistence agriculture, and trailed on trees and other supports. Also intercropped with maize, vegetables, etc.

PROPAGATION

Yams are propagated by means of small tubers or tuber cuttings of 0.2 to 0.5 kg weight, called "setts". In *D. esculenta* and *D. trifida* which produce a number of small tubers, a whole tuber is used as a sett. In the case of others, it is common practice to harvest immature tubers from the growing plant, leaving the top of the tuber intact, which will then form new tubers. Setts from the top of the tuber (proximal end) sprout more quickly and give higher yields than from other portions. It is a usual practice in India to dip the cut tubers in cowdung slurry and dry in the shade for a day prior to sowing; the treatment is supposed to have insecticidal and nutritive advantages.

LAND PREPARATION Usually planted on mounds or hills; the size and height of the mounds vary greatly, but usually they are 50-100 cm high and 75-150 cm in diameter. On sloping lands, ridges are preferred. In Southeast Asia, yams are also planted in trenches filled with topsoil and organic matter.

SOWING Usually one sett per mound, but, on large mounds, 3-4 setts are planted; mounds are at about 1 x 1 m spacing, and ridges 1.5 m apart with 0.5 m between plants along the ridges. Number of setts per hectare is 10,000-15,000. Planting is usually done towards the end of the dry season. It is a common practice, especially under West African savanna conditions, to mulch the top of the mounds with dry leaves, straw, grasses etc.

NUTRITION The normal practice is to apply farmyard manure and organic matter before planting; [illegible]5-50 tons/ha are given. In fertilizer trials in all growing regions, good response to N has been reported. Fertilizer mixtures high in N and K and top-dressing with N have been recommended for good yields.

AFTERCARE Plants that are supported for trailing on to trees, poles, bamboo, or a growing support are reported to yield well. Strings are provided for the vines to climb up the trees when trees are used as the support.

HARVESTING The maturity of tubers is indicated by drying of the leaves and gradual withering of the stem. The time taken for maturity depends upon the species and cv. Under homestead conditions, staggered harvesting is possible on a limited scale. The tubers should be free of cuts and bruises to facilitate storage.

STORAGE In places like West Africa, where yams are the staple crop, the tubers are stored for several months by tying them to vertical wooden structures so as to facilitate adequate ventilation and check against termite attack. During storage, the tubers lose weight - up to 30% in six months - due to respiration and shrinkage.

YIELD Yields vary considerably, depending upon cultivation practices and cvs. Usual yields are 7.5-18 t/ha in West Africa, 12.5-25 t/ha in Southeast Asia and 20-30 t/ha in the West Indies.

PESTS AND DISEASES

Yam beetles (the most widespread of which is *Heteroligus meles*, whose adults feed on the tubers), various fungi causing leaf spots, and storage rot affecting stored tubers are the serious threats. Nematodes also cause considerable damage, especially *Meloidogyne* spp., *Scutellonema bradys* and *Pratylenchus* spp.

AGROFORESTRY POTENTIAL

Yams are of great value in agroforestry because of their food value, adaptability to growing under trees, relative ease of management, etc.

MAJOR RESEARCH INSTITUTIONS AND REFERENCES

The Indian Institute of Horticultural Research, Bangalore, and the Central Tuber Crops Research Institute, Trivandrum, are the two national (ICAR) institutes doing research on yams in India.

National Root Crops Research Institute, Umuahia, Nigeria.

There are several research units in other yam-producing countries.

Proceedings of the Symposia of the International Society for Root and Tuber Crops and tropical agricultural research journals publish research findings on yams. Other major references include:

Coursey, D.G. 1967. Yams. Longman, London.

Kay, D.E. 1973. *In* Root crops. TPI Crop and Product Digest No. 2. Tropical Products Institute, London.

Waitt, A.W. 1963. Yams, *Dioscorea* species. Field Crop Abstracts 16, 145-157.

FRUITS

BANANA

SCIENTIFIC NAME	*Musa* spp. Family *Musaceae* 2n = 22, 33, 44
COMMON NAMES	Banana, plantain (E) Banane, plaintain (F) Banana, plátano (Sp)

USES AND ECONOMIC IMPORTANCE

Bananas are the most important tropical fruit crop, and form one of the biggest single items in international fruit trade. Banana is the staple food in many parts of Africa. It is eaten raw when ripe, while unripe fruits are cooked, both providing a starchy food; the former form is called banana and the latter plantain, though botanically most of the fruits eaten are bananas and the names are used differently in different parts of the world. Beer and sweetmeats of various kinds are made from banana. After removal of the outer bracts, the male buds are boiled and eaten as a vegetable in parts of Southeast Asia. Fibre can be extracted from the pseudostem; split pseudostem is a good mulch in plantations, and the sap can be used as a marking ink.

ORIGIN AND DISTRIBUTION

Banana originated in humid tropical Asia. It is now grown throughout the tropics for local consumption; the largest area is in Africa, which accounts for about 50% of the total world production; Asia and America account equally for the rest. The biggest producer is Uganda. Most of the bananas that enter international trade are produced in Central and South America and the Caribbean.

PLANT CHARACTERISTICS

A perennial herb, 2-9 m tall; has a corm, a pseudostem, and a terminal crown of leaves through which the inflorescence emerges. Root system is shallow and forms a dense surface mat to 15 cm depth; roots are adventitious, somewhat corky when mature, 5-8 mm in diameter, about 200-400 per plant and produced from the corm.

The underground stem (corm) has little lateral growth, and is covered with closely packed leaf scars. Leaves are produced in spiral succession from the terminal growing point and finally the centre of the meristem is transformed into inflorescence. Buds are produced opposite each leaf, and a few develop into secondary corms with shoots or suckers and emerge close to the parent plant, thus giving a clumped appearance. Suckers that originate from the upper part of the parental corm soon develop with large green leaves; these are called water suckers. Those from the lower part of the corm have initially pale, pointed, small leaves and are called sword suckers.

The pseudostem, composed of tightly packed leaf sheaths, is functionally the stem of the plant, and it varies in height from 2-8 m.

The leaf sheath gradually contracts into a petiole, and a broad lamina with a stout midrib. Leaves are borne in a left-handed spiral with a 1/3-4/9 phyllotaxy. Lamina of mature plant varies from 150-400 x 70-100 cm depending upon the cv. The leaf emerges as a rolled cylinder in an upright position, slowly unfurls in 6-8 days and gradually becomes horizontal and then lowers. There are 10-15 functional leaves. At the end of the vegetative phase, the leaves become shorter.

The inflorescence emerges about 7-10 months (up to 18 months in high altitudes) after planting a 5-7 month-old sucker. The growing point at the base of the pseudostem is transformed into an inflorescence and it pushes through the centre of the pseudostem and emerges in the centre of the leaf crown in about 30-45 days. After emergence, the inflorescence becomes pendant (drooping).

The inflorescence is a complex spike and consists of a stout peduncle and cluster of flowers arranged spirally, but not encircling the peduncle, each cluster subtended by a large brown-to-reddish coloured bract which withers off after the flowers fall off. The first few nodal clusters produce female flowers and the distant nodes produce male flowers. The bracts and flowers open in sequence and the peduncle elongates progressively until the mature bunch is formed, consisting of a few hands of fruits at the basal and a long bare axis at the distal end, with a growing point that continues to produce bracts and male flowers.

The fruit is a berry, and in cultivated edible bananas, parthenocarpic fruits are developed without pollination. Most clones are female-sterile. But both male and female flowers, which open during the night, produce an abundant nectar that attracts bats, birds, and bees, wasps and other insects which aid in pollination (mostly self-pollination).

The fruit bunch matures within about 100 days after shooting of the inflorescence. Each cluster of fruits at a node is called a 'hand' and individual fruits 'fingers'. The number, shape, skin colour, size, flavour, etc. of fruit vary with the cultivar.

CULTIVARS Cultivated banana is usually referred to as *Musa sapientum* L. (syn. *M. paradisiaca* var. *sapientum* (L) Kuntze), and plantains as *M. paradisiaca* L. It is considered more appropriate to use the genome classification instead of the Latin one. About 300 clones are thought to exist: they are either diploids (AA Group) or triploids and triploid hybrids. The agriculturally significant cvs belong to the triploid groups and hybrids and include Gros Michel (the best bananas in the world) and the Cavendish subgroup. Tetraploid (AAAA Group) bananas have been produced by breeding small groups of diploid hybrids (AB), and triploid hybrids (AAB) have also been produced, mostly in India. The plantain subgroup, which is of importance in South India, belongs to the AAB Group.

ECOLOGY

CLIMATE Bananas prefer tropical humid lowlands; they are grown between 30°N and S of the equator from sea level to 1000 m; they can be grown at elevations up to 1200 m, but at higher elevations growth is poor. Optimal temperature is 27°C; an average, well-distributed rainfall of 2000-2500 mm per annum is considered satisfactory. Bananas are subject to wind damage and it is preferable to plant wind breaks in areas with strong winds.

SOIL Well-drained soils with good fertility and an assured supply of moisture are the best-suited. Deep and retentive loams, often of volcanic or alluvial origin with pH above 5, are preferred.

PHYSIOLOGY AND COMPOSITION

Bananas require good supply of sunlight, but there is no evidence of photoperiodicity. They do not tolerate waterlogging, high temperatures and frost.

Nutritionally, banana is similar to potato. The edible pulp of ripe banana contains about 70% water, 27% carbohydrates, 1.2% protein and 1% ash. The carbohydrate, which is stored as starch, is converted to sugars (glucose and fructose) on ripening. Bananas are rich in vitamin A, fair in vitamin C, and poor in vitamin B.

AGRONOMY

CROPPING SYSTEM Banana is planted both in pure stands and in mixed stands with other crops. In Africa, it is invariably interplanted with maize, beans, potatoes and other food crops. It is also grown as a 'nurse' crop (to give shade and protection) for cacao, coffee, etc. However, bananas are not considered the ideal shade plants for coffee because of the possible overlapping or the root systems.

PROPAGATION Banana is propagated vegetatively, but the planting material varies widely in different parts of the world. These include pieces of rhizomes (known as "bull heads" in Jamaica) weighing about 2.5 kg each, very young suckers (peepers) with only scale leaves, sword suckers and water suckers; maiden suckers, which are taller, 5-8 month-old suckers, are planted after removing all opened leaves and sometimes the top portions of pseudostem. While selecting suckers for planting, it is important that as much of the rhizome as possible is attached to the sucker. A uniform type of planting material tends to produce a uniform crop.

PLANTING Planted in hand-dug planting holes of about 60 cm depth and diameter, the holes being deeper in heavy soils. The holes are filled with topsoil, organic matter and phosphate fertilizer. Suckers are planted about 30 cm deeper than they were while attached to the mother plant. Time of planting depends upon the local climatic conditions. In dry areas, planting may be done at the beginning of the rainy seasons. Planting can also be adjusted to suit market conditions.

SPACING Spacing also varies considerably depending upon the clones (Gros Michel and such big clones require wider spacing), soil characteristics (fertile and good soil can support more plants per unit area), moisture pattern (wider spacing in dry areas) management practices (weeding, pruning, mechanization) etc. The usual spacing is 3-3.5 m square for bigger plant types. Hedge planting is practised in some places.

MANURING Banana is a heavy feeder and needs considerable amounts of N and K. Fertilizer recommendations vary considerably. N may be applied in small quantities at frequent intervals, and P and K at the time of planting. A fertilizer dose of 500 g N, 200 g P_2O_5 and 1000 g K_2O per plant is an average rate. Fertilizers are scattered in a ring around each stool and raked into the soil.

AFTERCARE Bananas require about 25 mm of water per week for successful growth, and when natural rainfall is not adequate, it is supplemented by irrigation.

Mulching is a common practice, and old banana pseudostem, leaves etc. are the common mulching materials. However, mulch is not allowed to come into contact with banana 'stems' so as to minimize weevil attack.

Aftercultivation, if done, should be shallow because banana has a shallow root system. Pruning and removal of unwanted suckers may be done regularly. Usually only 2-3 healthy suckers are retained per plant. Staking the maturing plant with forked poles is done to prevent bending due to weight of the heavy bunch; the male part of the inflorescence is removed after the bunch has been fully formed.

HARVESTING. Some clones change colour when the bunch is ripe, but others remain green. The bunch is harvested carefully without bruising the fruits. The stage at which the bunch is harvested depends on the use - fruits for cooking can be harvested before they are fully ripe.

YIELD

Yield varies considerably. On average, about 1500 bunches of about 20 kg each can be obtained per hectare from a planted crop. With good husbandry, the yields can be much higher.

The life of the banana plantation varies from 3-15 years; on a commercial scale, it takes 5-8 years before the field may be replanted or changed.

PESTS AND DISEASES

The most serious disease is Panama disease or banana wilt, caused by the fungus *Fusarium oxysporum* f. *cubense*. It has caused widespread damage, particularly in Central America and the West Indies. Planting disease-free suckers is the most effective remedy. Leaf spot caused by *Mycosphaerella musicola* (Imperfect stage: *Cercospora musae*) and bacterial wilt caused by *Pseudomonas solanacearum* are the other serious diseases. Bunchy top virus, transmitted by the aphid *Pentalonia nigro-nervosa*, causes serious damages in Asia, the Far East and Australia.

The major pest is the banana weevil *Cosmopolites sordidus*.

The burrowing nematode *Radopholus similis* has also assumed serious 'pest' proportions.

A number of mineral deficiency diseases also occur.

AGROFORESTRY POTENTIAL

The importance of bananas in agroforestry is due to their tolerance to partial shade as well as the ability to provide shade to other crops during the early growth of such species.

Moreover, bananas are adaptable to a wide range of conditions and can be easily cultivated.

MAJOR RESEARCH INSTITUTIONS AND REFERENCES

A number of institutions throughout the world carry out research on various aspects of banana production and improvement; a large volume of literature is also available.

The journals Tropical Agriculture Trinidad, and Fruits contain a considerable volume of literature on banana.

Simmonds, N.W. 1966. Bananas. 2nd ed. Longman, London.

FRUITS

BREADFRUIT

SCIENTIFIC NAME

Artocarpus altilis Fosberg
syn. *A. communis* Forst
A. incisa L.f.
Family *Moraceae*
2n = 56

COMMON NAMES

Breadfruit	(E)
Arbre à pain	(F)
Árbol del pan	(Sp)

USES AND ECONOMIC IMPORTANCE

Grown for the edible fruit, which is an important food in Polynesia; used as a vegetable; usually eaten after cooking; biscuits are also made from it. The timber is useful.

ORIGIN AND DISTRIBUTION

A native of Polynesia; now spread throughout the tropics; important in Polynesia and the West Indies.

PLANT CHARACTERISTICS

A striking monoecious tree up to 20 m high; evergreen in the ever-wet tropics; deciduous in monsoon climates; has latex in all parts. Roots adventitious; dense surface mat of feeding roots. Trunk straight with thick twigs, and pronounced leaf and stipule scars. Profuse foliage, leaves large 30-60 x 20-40 cm, thick, spiral arrangement with 2/5 phyllotaxy, pinnately cut and several-lobed. Inflorescence axillary, club-shaped, 15-25 cm long, male inflorescence drooping on stout 3-8 cm long peduncle with minute flowers. Female inflorescence stiffly upright on stout peduncle with numerous flowers embedded in receptacles. Fruit is a syncarp formed from whole inflorescence, oblong, 10-30 cm in diameter, yellowish-green rind with hexagonal reticulous markings and sometimes short spines.

The fruit has a central core surrounded by numerous abortive seedless flowers, which form the edible portion. Flowers are wind-pollinated; hand-pollination results in better fruit set and larger fruits. Fruits will set without pollination also, but the fruits so produced are small.

Very little scientific breeding work has been done for the crop. The cvs from several territories in the South Pacific have been collected to identify and select early, late, or year-round producing cvs.

ECOLOGY

Breadfruit is a tree of the humid tropical lowlands, thriving best in areas of 150-250 cm rainfall, preferably all the year around, and in temperatures of 22-34°C. The trees are grown on a wide variety of soils, but they do not withstand very shallow soils and waterlogging.

PHYSIOLOGY AND COMPOSITION

Very little is known about specific physiological characteristics. But the young plants require shading and grow well under the shade of other trees; later they require full exposure.

The edible portion, which constitutes about 70% of the fruit, contains about 20% carbohydrates, 1.8% fibre and 1.3% protein.

AGRONOMY

Propagated vegetatively (usually no seed setting) by root cuttings of about 2-3 cm diameter and 20 cm length, which are planted either horizontally or slantingly in shaded moist beds; well-transplanted about 8-10 m apart. The tree grows rapidly and begins to bear when it is 3-5 years old. The fruits are ready for harvesting about 2-3 months after the emergence of the inflorescence, when they are still firm; the main harvesting season lasts about 4 months.

YIELD

Trees yield up to 700 fruits per year, each weighing 1-4 kg.

PESTS AND DISEASES

No serious pests or diseases; soft rot of the fruits caused by *Rhizopus artocarpi* has been reported from India. Also, immature fruits drop off occasionally.

AGROFORESTRY POTENTIAL

Breadfruit is a good tree for agroforestry in homestead gardens; the canopy is dense and luxuriant, but it offers good shade under which poultry can be reared. Moreover, crops like greater yam *(Dioscorea alata)* can be cultivated underneath, and trailed on to the mature trees.

MAJOR RESEARCH INSTITUTIONS AND REFERENCES

Institutions in Rodovia, Brasilia, Brazil; Santa Rosa, Chile; San Jose, Costa Rica; and the Agricultural Universities in the southern parts of India carry out some research on breadfruit.

Coenan, J. and Barrau, J. 1961. The breadfruit tree in Micronesia. South Pacific Bull., Oct. 1961, 37-39.

Singh, S., S. Krishnamurthi and S.L. Katyal. 1963. Fruit culture in India. Indian Counc. Agric. Res., New Delhi.

Fig. 18. Papaya (Photo credit: Centre d'Etude de l'Azote, Zurich).

FRUITS

PAPAYA

SCIENTIFIC NAME	*Carica papaya* L. Family *Caricaceae* 2n = 18
COMMON NAMES	Papaya, papaw, pawpaw (E) Papaye (F) Papaya (Sp)

USES AND ECONOMIC IMPORTANCE

Ripe fruits are eaten fresh for breakfast, dessert and in fruit salads throughout the tropics. Unripe fruits are cooked as a substitute for marrow and for apple sauce. Papaya is also grown for the enzyme papain which is extracted from dried latex of immature fruits. The enzyme is used as a meat tenderizer, in the preparation of chewing gum, as a drug for digestive ailments etc. Young leaves are sometimes used as a vegetable and the seeds as a counter-irritant and abortifacient.

ORIGIN AND DISTRIBUTION

Papaya is not found in the wild state; it is believed to have originated in South Mexico and Costa Rica. Today it is cultivated throughout the tropics. Sri Lanka, Tanzania, Uganda and Hawaii are the major producers.

PLANT CHARACTERISTICS

A short-lived perennial, 2-10 m tall, unbranched, erect, cylindrical, soft-wooded, hollow stem with prominent leaf scars; leaves are clustered near the apex of trunk; they are spirally arranged and have long (25-100 cm) petioles; and the lamina has 7-11 palmate and deep lobes and prominent veins. Plants are usually dioecious or rarely hermaphrodite. Male flowers are produced in pendant axillary panicles, 25-75 cm long. Female flowers are short (3-5 cm long), axillary and short-stalked, borne singly or in few-flowered cymes. Hermophrodite flowers externally resemble female flowers. The proportion and type of flowers produced on the same tree can vary depending upon its age, season etc. Male and hermophrodite trees undergo sex reversal, but not female trees. Female sterility is favoured by warm weather and such trees become female fertile in cool weather. If hermaphrodite flowers are self-pollinated, the seeds produce hermaphrodite and female plants in the ratio 2:1.

Fruit is a fleshy berry, 7-30 cm long, ovoid-oblong, weighing up to 9 kg with thin smooth skin, green in colour, turning yellowish or orange when ripe; the central cavity is 5-angled. Many spherical dark or greyish seeds are attached to the interior wall in 5 rows; there are about 20 dried seeds per gram.

There are several cvs, but these are difficult to maintain in dioecious plants. Hermaphrodite types can be maintained true to type by self-pollination.

Plants flower 4 months after planting and the fruits are ready after another 6 months. Although the trees live up to 20 years, yields decline with age. Economic life span is 5-6 years.

ECOLOGY

Papaya is a tropical plant, grown between 30^{o}N and S latitudes, at elevations from sea level to 2000 m near the equator, and in areas with a wide range of rainfall. For papain production, lower altitudes are preferred. Good supply of soil moisture is essential. Papaya prefers a well-drained fertile soil with pH 6-6.5; it cannot withstand frost and waterlogging.

PHYSIOLOGY AND COMPOSITION

Being a soft-wooded plant with hollow trunk, it is subject to wind damage. It does not tolerate waterlogging and extreme climates. High temperatures induce female sterility. The plant tolerates light shade.

The edible portion of the fresh fruit contains approximately 88% water, 10% sugar and 0.5% protein. It is rich in vitamins A and C.

AGRONOMY

Papaya is cultivated on homesteads, field bunds, or plantations.

It is usually propagated by seeds; vegetative propagation, though possible, is not usually practised. Seeds are sown in nursery beds or plastic or wooden containers, and are ready for transplanting 8-10 weeks after sowing, when they will be 15-20 cm tall. Usually 5-7 seedlings are planted per hole 2.5-3.5 m apart; after about 6 months when sex can be determined on flowering, all except one female plant per hill are removed. Sometimes seeds are sown at stake, 10-30 seeds per hill and eventually only one female plant is retained. For every 15-25 female plants, one male plant is also retained. In cvs like 'Solo', only hermaphrodite plants are retained in order to get fruits of uniform size and shape.

Transplanting is usually done in the rainy season. Irrigation during dry months and mulching are beneficial. In Hawaii, 8-12-6 NPK mixture at the rate of 1 kg per tree per year is recommended. Occasional thinning of fruits is necessary to prevent overcrowding. Bearing commences by the end of the first year. Fresh fruits are harvested with a sharp knife when the first traces of yellow appear on the skin. Fruits are produced throughout the year.

Papain is obtained by tapping unripe fruits of at least 10 cm diameter, by making 3-4 longitudinal cuts of about 3 mm depth. The latex is collected in trays with wooden frames and canvas or polythene linings, which are clamped to the trunks. The latex coagulates in the trays, is scraped with a wooden scraper, and is dried quickly in the sun or in special ovens at 55-60°C for 5-7 hours. Tapping is not done in hot weather; mature fruits do not yield latex; fruits tapped once are tapped again at weekly intervals; tapping is usually done for two years only; the plant gives 50% of latex yield during the first year of tapping.

YIELD

Yield varies from 30-150 fruits per year per tree, giving up to 400 t marketable fresh fruits per ha per annum.

Yield of dried latex is about 150 kg/ha p.a. under ideal conditions.

PESTS AND DISEASES

Papaya is comparatively free of pest attack; but diseases such as mosaic virus, collar and foot-rot caused by the fungi *Pythium* spp., and anthracnose, caused by *Colletotrichum* spp., cause considerable damage at times.

AGROFORESTRY POTENTIAL

The crop has good agroforestry potential as it is suitable for intercropping and hedge planting on the border of agricultural fields. It is relatively free of pests and diseases, easy to manage and it gives quick returns. However, it is not suited for marginal conditions of soil and climate.

MAJOR RESEARCH INSTITUTIONS AND REFERENCES

The Indian Institute of Horticultural Research, Bangalore, India; the Agricultural Research Centre for Humid Tropics (CPATU), Belém, Brazil; the University of Hawaii; and the Agricultural Research Station, Boralanda, Sri Lanka are some of the leading institutions conducting research on papaya.

Becker, S. 1958. The production of papain - an agricultural industry for tropical America. Econ. Bot. 12, 62-79.

A few publications in the East Afr. Agri. For. Journal.

FRUITS

PASSION FRUIT

SCIENTIFIC NAME	*Passiflora edulis* Sims Family *Passifloraceae* 2n = 12
COMMON NAMES	Passion fruit (E) Passiflore (F) Fruta de la pasión (Sp)

USES AND ECONOMIC IMPORTANCE

The juice of passion fruit is a very popular beverage. The yellow gelatinous pulp around the seed is used for making jams and jellies and in sherbets, and the fruit is eaten directly or used in fruit salads.

ORIGIN AND DISTRIBUTION

Passion fruit is a native of southern Brazil. It is now commercially grown in Australia, South Africa, New Zealand, Hawaii and Brazil.

PLANT CHARACTERISTICS

The plant is a woody perennial climber, up to 15 m long with green, grooved stem and axillary, robust, spirally coiled tendrils. The lamina is deeply palmately 3-lobed, 10-15 x 12-25 cm, but undivided in young plants. Flowers are axillary, fragrant and showy, about 10 cm in diameter. The fruit is a berry, globose or ovoid, 4-6 cm in diameter, deep purple when ripe, dotted and hard but with a thin pericarp. There are many seeds, surrounded by yellowish aromatic pulpy juice with a pleasing flavour. Passion fruit is cross-pollinated by bees, wasps, and humming birds. The economic life-span of the plant is 5-6 years.

Two forms have been recognized:

P. edulis f. *edulis* is the common purple passion fruit. It has a better flavour, especially when eaten directly, and it does well at higher altitudes (of about 1800 m) in the tropics; it does not grow well in wet lowlands.

P. edulis f. *flavicarpa* is the yellow passion fruit, which is slightly larger (5-6 cm diameter); the pulp is more acidic, and is better suited to tropical lowlands.

P. quandrangularis, the giant grandiflora, is a similar species giving much larger fruits, and growing at low altitudes.

ECOLOGY

An average annual rainfall of 750 to 1250 mm is ideal; the crop does not fruit well in regions with heavy rains because the pollen grains burst on contact with water, and thus rains prevent pollination.

The purple passion fruit does best in the tropical highlands while the yellow form tolerates lower altitudes. Passion fruit grows on a variety of soils, but does not grow well on very heavy and poorly drained soils.

PHYSIOLOGY AND COMPOSITION

Not much is known about the physiology of the crop with respect to its shade tolerance and adaptability to specific conditions. Fruits are produced on new growth of shoots.

The pulp and seeds contain approximately 72% water, 2.4% protein, 2.8% fat, 17% carbohydrate and 4% fibre.

AGRONOMY

Passion fruit, being a climber, is trained on trellises made of posts and wire 2-3 m apart and 2-3 m high, so that the vines provide partial shade which can be used with advantage during the early stages of growth of crops like cacao.

Usually propagated from seeds (but can also be propagated by 2-3 internode-long stem cuttings), which are thickly sown in nursery beds and shaded. Seédlings at the two-leaf stage are transferred to pots, baskets or polythene bags, and are transplanted when about 30 cm tall and 3-4 months old. The seedlings are planted 3-5 m apart and two leaders are allowed to grow from each seedling to reach the wire. The plants are sometimes pruned to induce the growth of new shoots. In Hawaii, a 10:5:20 NPK fertilizer mixture is recommended at the annual rate of

1 kg per plant.

During the first year, only a few fruits are produced. Thereafter, there are two main fruiting seasons per year. The fruits mature in 2-2½ months after pollination, and are allowed to fall on the ground and are picked up every 2-3 days. The fruits can be kept for about one week without deterioration before processing. In the preparation of juice, the pulp is extracted from the fruits and the seed is separated from the juice by centrifuging.

The commercial life span of purple passion fruit is 5-6 years.

YIELD

Average yield is about 20,000 kg fresh fruits per hectare; they contain 30-40% by weight of juice, and about 4 kg fruits are required to produce 1 litre of juice.

PESTS AND DISEASES

Woodiness disease, supposed to be caused by an aphid-transmitted virus, is the major disease. Brown spot, caused by *Alternaria passiflorae*, which causes defoliation as well as spotting of the fruits, also assumes serious proportions.

Different types of fruit flies puncture the young fruits and cause immature fruit crop.

AGROFORESTRY POTENTIAL

Passion fruit has agroforestry potential because it can be used to provide shade to other species when they are young, and it could also be grown under the partial shade of trees.

REFERENCES

Chapman, T. 1963. Passion fruit growing in Kenya. Econ. Bot. 17, 165-168.

Lippman, D. 1978. Cultivation of *Passiflora edulis*. S. German Agency for Technical Cooperation (GTZ), Eschborn (Fed. Rep. Germany).

University of Hawaii. 1954. Passion fruit culture, Ext. Cir. 354.

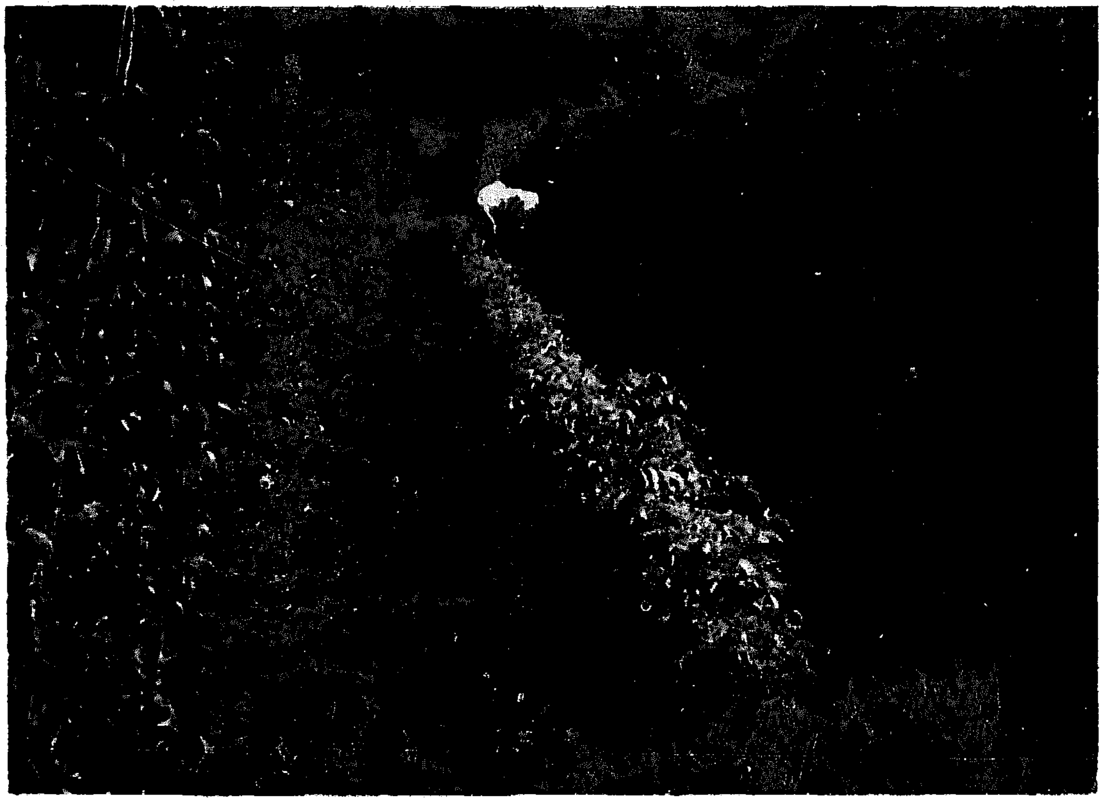

Fig. 19a. Passion fruit and potato, Kenya.

Fig. 19b. Passion fruit and pyrethrum, Kenya.

FRUITS

PINEAPPLE

SCIENTIFIC NAME	*Ananas comosus* (L.) Merr. syn. *A. sativus* Schult. Family *Bromeliaceae* 2n = 50
COMMON NAMES	Pineapple, ananas (E) Ananas (F) Piñas, ananás (Sp)

USES AND ECONOMIC IMPORTANCE

Popular dessert fruit also used by the canning industry for juice and jam. Fresh fruits contain a protein-digesting enzyme bromelain, but it is not produced commercially. The leaves yield a strong white silky fibre used for a fine fabric called pina cloth in Southeast Asia in village industry. The fibre is not produced economically from plants grown primarily for fruits. Young fruits are sometimes used as an abortifacient.

ORIGIN AND DISTRIBUTION

Believed to have originated in South America in the Parana-Paraguay river delta. Now grown widely throughout the tropics and subtropics; the major producing regions are Hawaii, Southeast Asia, Brazil, East and southern Africa, and Australia.

PLANT CHARACTERISTICS

It is a perennial herb of about 1 m height with a leafspread of 130-150 cm and a terminal inflorescence and fruit. In natural conditions, axillary buds in the leaf axils grow into vegetative branches and produce fruits while still attached to the parent plant. The plants may continue living and fruiting for several years. In commercial production, however, only one or two ratoon crops are taken.

Roots are fibrous and superficial, seldom going below 60 cm. Stems are short and thick, 20-25 cm long, usually curved at the base in plants grown from shoots and slips. Leaves are arranged in a right- or left-handed spiral with a 5/13 phyllotaxy. Leaves at the base elongate up to about 1 m, younger leaves being shorter. Some cultivars have spines along the leaf margins. The upper surface of the leaf is smooth and dark-green, whereas the lower surface is silvery white and scurfy.

Inflorescence is produced at the tip of the stem 12-18 months after planting depending upon the planting material used (see propagation). Peduncle stout, 7-15 cm long; flowers 100-200 in number, hermaphrodite. Flowers open 5-10 per day from the base of the inflorescence upward.

The fruit is a parthenocarpic multiple fruit or syncarp formed by almost complete fusion of 100-200 berry-like fruitlets, subtending leafy bracts to each other and to the central fibrous axis or peduncle of the inflorescence. Mature fruit is broadly cylindrical, tapering slightly towards the tip, about 20 cm long, 14 cm in diameter and 1.5-2.5 kg in weight. The fruits carry a crown of small leaves, formed by continuation of growth of the peduncle. Growth of the crown continues during fruit development, but ceases when fruit is mature and becomes dormant. Cultivars are seedless when grown in pure stands, but 2000-3000 seeds may be produced when natural or hand-pollination takes place. Flowers are self-incompatible, and pollination is mostly by humming birds.

A large number of cultivars have been recorded. Cayenne is the most widely grown cv.; others are Queen (Australia and South Africa), Red Spanish (in Central America), Singapore Spanish (Malaysia), Abacaxi (Brazil), etc.

ECOLOGY

CLIMATE Mostly grown at low elevations between 25°N and S in areas with a temperature range of 15-30°C. Pineapples cannot withstand frost, and very little growth takes place below 20°C and above 35°C. In Kenya, they are grown at elevations from 1400-1800 m; the fruit is too sweet at lower altitudes and too acid at higher altitudes, both being unsuitable for canning.

Pineapples are tolerant of drought because of the special water storage cells. They can be grown within a wide range of rainfall from 600-2500 mm per annum, the optimum being 1000-1500 mm.

SOIL Can be grown on a wide range of soils, but do not tolerate waterlogging. Sandy loams with a pH of 5-6.5 are preferred.

PHYSIOLOGY AND COMPOSITION

Because it can withstand drought and be grown in partial shade, pineapple is a good crop for agroforestry.

About 60% of the fresh fruit is edible and the edible portion contains about 14% sugar.

AGRONOMY

CROPPING SYSTEM Usually grown as a sole crop in plantations in commercial production, but can also be grown as an understorey crop in tree crop areas in small holdings. The normal crop cycle is 3-4 years, consisting of one planted crop and one ratoon crop.

PROPAGATION Propagated vegetatively by crowns, slips, suckers or shoots. Crowns are produced on the top of the fruit normally at the rate of one per fruit. Slips are leafy shoots borne on the peduncle on the base of the fruit or just below. They develop only on vigorous, healthy plants and they increase in length after the fruit is harvested. Those that weigh about 400 g are best for planting, and 2-3 can be obtained from a healthy plant. Suckers develop from the buds below or just above the soil surface at the same time as inflorescence, usually 2-3 per plant; those weighing 200-300 g are best for planting. Shoots are leafy branches arising from buds in the leaf axils, 0-3 per plant, and are suitable for planting when 30-35 cm long; if left on the plants they produce a ratoon crop.

The planting material, after removal from the mother plant, may be dried in the sun for 1-2 weeks to make it more sturdy and resistant to butt rot. It may also be treated with insecticides to control mealy bugs and other insects.

The length of the period from planting to maturity depends upon the planting material - 15-16 months for shoots, about 18 months for suckers, 20 for slips and 22-24 for crowns. Thus it is possible to spread the harvest season by using different planting materials. Crowns produce the most uniform crop.

LAND PREPARATION Deep cultivation is considered desirable. A fine tilth and smooth surface are necessary if mulching paper is used. When replanting, the remains of the old crop are chopped up and incorporated to the soil.

PLANTING, PLANT POPULATION Usually planted in beds (sometimes in shallow trenches), each with two rows about 50 cm apart, with 40 cm between each plant in a row, plants in adjacent rows alternating, and a distance of 90 cm between beds. About 40,000 plants are planted in one hectare. In commercial production, mulching with black polythene is a regular practice; it improves the growth of pineapples, suppresses weeds, conserves moisture and increases soil temperature. The mulch is laid in strips before planting, separately for each bed, and the plants are inserted through the mulching paper.

NUTRITION Heavy applications of fertilizers, especially nitrogen, are needed: usually about 100-150 kg N/ha per year, applied in equal instalments every 3-6 months, and about 100 kg and 60 kg P_2O_5 per hectare in two instalments. In Australia, 1500 kg/ha of 10:6:10 NPK mixture is applied in an annual dressing supplemented with 50 kg N/ha in two instalments.

AFTERCARE Weeding is an important operation, and is done with a combination of mulch, herbicides, and hand-weeding. Irrigation is seldom practised. Around the time of harvesting, unwanted slips and suckers are removed in a process called "stripping". For a ratoon crop, only one healthy sucker, originating from below the ground, is retained. In commercial plantings, uniform flowering is induced by spraying hormones (NAA or its sodium salt at the rate of 10-100 ppm) after floral differentiation. Maturing fruits are protected from sun-scorching and rodent attack by covering them with the old leaves of the plant.

HARVESTING Mostly by hand, but also done mechanically in Hawaii. Fully ripe fruits can be easily detached from the stem by hand. Fresh fruits are marketed with the crowns intact.

PROCESSING The base of the fresh fruits is sometimes treated with benzoic acid and talc to prevent fungal rotting caused by *Thielaviopsis paradoxa*. Most pineapple is canned in producing countries, for which the central core and the 'shell' of the fruit are removed. The juicy flesh is cut or sliced and sterilized, and hot syrup made from juice and sugar is added. Also canned as fruit salads and in mixed fruits.

PESTS AND DISEASES

Mealy bug wilt caused by *Dysmicoccus brevipes* and *D. neobrevipes* is the most serious disease of pineapple. It is believed that the mealy bug is the vector carrying the virus that causes the rot. The symptoms appear as rot of the roots, followed by wilting of leaves. Control of the mealy bug is the best way to control the disease. Heart and roots rot is caused by *Phytophthora cinnamomi*, whereas butt rot is caused by *Thielaviopsis paradoxa*.

Root knot nematodes, *Meloidogyne javanica*, and other nematodes, particularly *Rotylenchulus reniformis*, cause considerable damage, and they can be controlled by soil fumigation.

Rats and rodents damage the crowns and maturing fruits.

AGROFORESTRY POTENTIAL

Pineapple is grown both as a smallholder crop and on a plantation scale. It can withstand drought as well as partial shade. It gives a reasonable yield even under marginal conditions. Thus, pineapple is a good species for agroforestry.

MAJOR RESEARCH INSTITUTIONS AND REFERENCES

There are several institutions in Brazil, Hawaii, India, Kenya and other pineapple-growing regions, that conduct research on the crop; many research publications are also available.

Collins, J.L. 1960. The pineapple. Leonard Hill, London.

Fig. 20a. Pineapple and bananas interplanted with 18 month-old rubber trees (Photo credit: Rubber Research Institute of Malaysia).

Fig. 20b. Pineapple interplanted with pines in Salvador, Brazil.

CASTOR

SCIENTIFIC NAME

Ricinus communis L.
Family *Euphorbiaceae*
2n = 20

COMMON NAMES

Castor	(E)
Ricin	(F)
Ricino	(Sp)

USES AND ECONOMIC IMPORTANCE

Castor is an oil seed: the seeds contain 40-55% of a non-drying oil, which is used for industry, medicinal, lubricating and lighting purposes. Industrial uses include coating fabrics and other protective coverings, dyeing of textiles, preservation of leather, manufacture of paints and varnishes, waxes, polishes, candles, etc. The cake (residue after crushing) is used as a manure; it is toxic due to the presence of ricin, but it can be used as a cattle feed after detoxication. Plant stalks are used as fuel, thatching material, and for preparing pulp and paper. In *eri* silk-producing areas, the leaves are fed to *eri* silk worms.

ORIGIN AND DISTRIBUTION

The castor plant is believed to have originated in North Africa and India. It is now grown in many parts of the tropical and subtropical world. Brazil is the largest producer, followed by India and Thailand. It is also cultivated in the USA, Egypt, Ethiopia, Tanzania, and many other Asian, African and Central American countries.

PLANT CHARACTERISTICS

An annual herb (to 1 m tall) or a short-lived perennial (up to 6 m); usually cultivated as an annual. Root system is well developed with a tap-root and prominent laterals and produces a surface mat of feeding roots. Stem is green or reddish; becomes hollow with age, and has distinct nodes and prominent leaf scars. The single stem that is produced first terminates in an inflorescence, and 2-3 sympodial branches grow out, one from each node immediately below the inflorescence; these branches also end in inflorescences and the sympodial branching continues. Thus the plant will have inflorescences at various stages of development.

Leaves are arranged spirally with 2/5 phyllotaxy, lamina orbicular, 10-75 cm in diameter, palmately divided for about half the length with about 5-11 lobes.

Inflorescence is a terminal, many-flowered penicle, 10-40 cm long; flowers are unisexual, with male flowers at the base and female flowers on top of the inflorescence. Female flowers open before the male flowers, so there is high degree of cross-pollination; mainly wind-pollinated. Each female flower produces a thick-walled spiny capsule with three loculi; each loculus contains one seed.

Seed is ovoid, dorsally compressed, shining, dark and mottled, very variable in size, 0.5 to 1.5 cm long; testa is brittle and forms about 20% weight of the seed.

ECOLOGY

CLIMATE Castor grows well in relatively dry, warm regions having a well-distributed rainfall of 500-750 mm. Heavy rainfall promotes excessive growth and the crop assumes a perennial habit. Castor is fairly drought-resistant, owing largely to its deep root system. It cannot tolerate frost and the crop needs at least 150-180 frost-free days. The crop is grown over a wide range of altitude in the tropics, up to 2000 m. In still higher altitudes, perennial varieties are grown for shade in coffee estates.

SOILS Grows well in all types of soils if they are well-drained; but it grows best in rich, well-drained, sandy-to-clayey loam and light alluvium.

PHYSIOLOGY AND COMPOSITION

Castor does not tolerate waterlogging and frost. Perennial varieties shatter seeds, but most annual cvs are non-shattering.

Castor oil contains 80-90% of ricinoleic acid which is not found in any other plant. On dehydration, a drying oil is produced which does not turn yellow on drying or baking, hence its value in paints and varnishes. The seed contains a toxic protein, ricin, which acts as a blood coagulant. The oil cake can, however, be detoxicated. Leaves also contain smaller quantities of ricin.

AGRONOMY

CROPPING SYSTEM Grown as a sole crop of the year in rotation with finger millet, groundnut, cotton, seame, etc. or mixed with one or more of these crops in the same or alternating groups of rows. It is also planted on the sides of irrigation channels and borders of garden crops, and allowed to stand as a windbreak for several years.

PROPAGATION By seed; good seeds retain their viability for 2-3 years. Germination is epigeal; emergence 7-10 days after sowing.

LAND PREPARATION Deep and thorough preparation of seed-bed is considered desirable.

SOWING, SPACING, SEED RATE In the USA, where dwarf cvs are used for mechanized production, the seeds are sown 4-8 cm deep, in rows 1 m apart, at a spacing of 20-25 cm between plants within the rows, and a seed rate of about 15 kg/ha. In India, with taller varieties, the rows are 1-1.5 m apart and the plants within the rows 60-80 cm, and the seed rate is 8-10 kg/ha. In Africa, three seeds per hole are dibbled at 0.9 x 0.3 m spacing, and later thinned to one plant per hole when the plant is about 25 cm tall.

MANURING, AFTERCARE Weeding is necessary during the first 1-2 months; sometimes plants are also earthed up. Castor responds to fertilizers. In the USA, 40-120 kg N/ha is usually applied in two splits. Fertilizer recommendations in India vary from 25-90 kg N, 25-75 kg P_2O_5 and 0-45 kg K_2O per hectare.

HARVESTING The crop matures in 6-8 months. For the crop sown in June-July, the capsules start ripening in December and continue doing so till March-April. When one or two capsules in a bunch start drying, the whole cluster is generally removed, stacked and covered. However, since immature capsules have a lower oil content, it is preferable to grow non-dehiscent types and collect the fruits as they ripen. When the whole crop is gathered, it is dried in the sun for a few days and the seed is brought out by beating with sticks.

The seed contains about 50% oil, about 85% of which is extracted if power expellers are used. The efficiency of recovery by local types of extractors is about 70%.

YIELD

In India, the average yield is about 600 kg of seeds per hectare; but can be up to 1000 kg/ha. In the USA, yields of 1200-2500 kg/ha are obtained. In Africa, yields of rainfed castor are in the range of 500-1000 kg of seeds/ha.

PESTS AND DISEASES

The castor semi-looper *(Achaea janata)*, the castor hairy caterpillar *(Euproctis lunata)* and the capsule caterpillar *(Dichocrosis punctiferalis)* are the serious pests of castor. Seedling blight caused by *Phytophthora colocasiae*, and leafspots caused by *Alternaria ricini* are the major diseases. Damage caused by pests and diseases is greater in areas with higher rainfall.

AGROFORESTRY POTENTIAL

Owing to its drought resistance, amenability to mixed cropping, relative ease of management and adaptability to a wide range of growing conditions, castor is a good species for agroforestry.

MAJOR REFERENCES

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OILS AND FATS

COCONUT PALM

SCIENTIFIC NAME	*Cocos nucifera* L. Family *Palmae* 2n = 32
COMMON NAMES	Coconut palm (E) Cocotier (F) Cocotero (Sp)

USES AND ECONOMIC IMPORTANCE

A major producer of vegetable oil. Total estimated world production is 3.3 million tonnes of copra (dried endosperm), equivalent to about 2.3 million tonnes of oil.

Also yields valuable by-products like coir, charcoal from the coconut shell, leaves for thatching houses, and shells and husks for fuel. Because of the multiplicity of uses of its products, the palm has been described as the "Tree of the Heaven", "one of Nature's greatest gifts to man", etc.

ORIGIN AND DISTRIBUTION

The coconut is believed to have originated in Southeast Asia. Now cultivated in the tropics, predominantly near sea-coasts, between 20°N and 20°S of the equator. The Philippines, India, Indonesia, Sri Lanka and the Pacific islands are the major producers.

PLANT CHARACTERISTICS

Thick, erect, unbranched, continuously growing stem, with a crown of fully and partially opened leaves. About 30 opened leaves, each 6 m long and containing about 200 leaflets of 90-135 cm length. The leaf primordium is initiated about 30 months before leaf emergence; about 12-14 leaves are produced per year and they are arranged with a 2/5 phyllotaxy.

The root-producing bole is about 90 cm long; there are about 7000 roots per adult palm. The root system extends up to 4-5 m from bole; but the majority of roots can be trained to be concentrated in an area of 2 m radius from the bole.

Each leaf axil produces a spadix with numerous male and female flowers. Inflorescence primordium is initiated about 36 months before the emergence of inflorescence. Flowering commences at 5-10 years of age. Monoecious; female flowers are few in number and towards the base of inflorescence; male flowers total up to 300. There are distinct, non-overlapping male and female phases, which prevent self-pollination. Mostly cross-pollinated by insects which are attracted by the nectiferous, sweet-scented flowers. The fruit is a fibrous, usually ovoid drupe.

The coconut of commerce consists of seed and endocarp, 10-15 cm in diameter, and 0.5-1.0 kg in weight. The fruit attains its full size six months after fertilization; after that the endosperm begins to form, which at first is thin and jelly-like. The mature endosperm is thick, firm, white, and 1-2 cm thick, and is firmly attached to the shell or endocarp. The centre of the seed is a large cavity, partially filled with sweet 'coconut-water', which is completely absorbed when the harvested nuts are stored for over about six months.

There are two distinct varieties - the *Tall* and the *Dwarf*. Several cultivars have been identified; different hybrids have also been produced and they are popularly cultivated.

ECOLOGY

CLIMATE Coconuts require an equable climate with high humidity, which is usually found near the sea. The ideal mean annual temperature is 27°C with 5-7°C diurnal variation; the palm does not withstand prolonged spells of extreme variations. A well-distributed rainfall of 1300-2300 mm p.a. is preferred; long periods of drought adversely affect growth and production.

With few exceptions, successful cultivation is limited to the tropics, between 20° parallels from the equator and at lower altitudes below 300 m.

SOIL Coconuts grow well on a wide variety of soils, but well-drained soils of at least 2 m depth with no hard pans are ideal. They tolerate salinity and a wide range of pH, from 5.0-8.0.

PHYSIOLOGY AND COMPOSITION

Coconut does not grow well under shade and does not tolerate prolonged waterlogging. Though it is said to withstand salinity, most coconut-growing soils are acidic. Because of the long time lag (about 3 years) between the initiation of flower primordia and the harvesting of ripe nuts, the productivity of the palm is considerably influenced by environmental factors during this period.

Tender coconuts, which when harvested for coconut-water give as much as 0.5 litre of water per nut. Coconut-water contains about 0.6 g sugar/100 ml and it is somewhat aerated as it is saturated with carbon dioxide that is derived from the respiration of internal tissues.

The fresh endosperm contains approximately 36% water, 4.5% protein, 41.6% fat, 13% carbohydrate, 3.6% fibre and 1% minerals. The copra has an approximate composition of 6.8% water, 7.6% protein, 63.7% fat, 16.1% carbohydrate, 3.8% fibre and 2.0% minerals.

AGRONOMY

CROPPING SYSTEM In commercial production, coconuts are cultivated in large estates, but the majority of the crop in India and the Philippines is in smallholdings, where it is grown mixed with various other annual and perennial agricultural species. Intercropping of varying intensities is found in different countries and pastures are sometimes established under the palms.

PROPAGATION By seed; completely ripe seeds of desirable characters, harvested from selected mother palms, are sown in nursery beds with well-drained (sandy, or sandy loam) soils 25-30 cm x 25-30 cm apart, centre to centre. Germination is slow and it takes 3-6 months for the shoots to emerge. Early germination is considered a sign of vigour in seedlings, and seedling vigour is important for quick establishment in the field and early bearing.

FIELD PLANTING Land clearing is necessary as coconuts do not establish well in thick vegetation. Usually the square system of planting is adopted at 7-9 m spacing for the *Tall* palms, thus providing 130-180 palms/ha. Large planting holes of about 1 x 1 x 1 m are dug and partially filled with bulky organic matter; year- to 18 months-old seedlings are planted and mulched. Watering is necessary during dry periods.

MANURING Manuring of the young palms before flowering is necessary for encouraging vigorous growth and early bearing, while adequate nutrition of bearing palms is necessary for sustained yield. Palms respond well to N and K, but there is little response to P. As mentioned earlier, effect of manuring and other cultural practices on yield are not apparent until after 2½-3 years. Regular manuring with 0.5 kg N and 1.0 kg K per palm is recommended annually; for best results, the fertilizers are applied in frequent instalments. Foliar analysis is used as a guide to fertilizer application in plantations. Critical amounts of nutrients in the 14th fully opened leaf (from top) as percentages of dry matter are: 1.8-2.0 N; 0.1 P; 0.8-1.0 K; 0.5 Ca; 0.3 Mg.

AFTERCARE Regular intercultivation of the interspace of pure stands of coconuts, by digging or harrowing, to control weeds, is a common cultural operation. The palms do not withstand prolonged drought; irrigation during dry months increases the yield considerably.

HARVESTING First harvest is usually 6-8 years after planting; harvesting is usually done by male climbers, but also by pig-tailed monkeys. Nuts that are 11-12-months-old are harvested for copra production; 6-7 months-old for tender nuts (the nut water is used for drinking). Usually there are 6-8 harvests of 12-14 bunches per year.

PROCESSING Copra is the main product and is prepared by dehusking the nuts and drying the split nuts in the sun for 60-80 h. Kiln drying is also practised. Good quality copra should contain less than 7% moisture. The other major product is coir, prepared from fibre extracted after retting the husks in water. About 85 kg of coir is produced from 1000 husks.

YIELD

Average yield is 40-60 nuts per palm in a year, and good yields (from high-yielding types) are up to 120 nuts. Palms producing an average of more than 500 nuts per year have also been found. Usually 5000-6000 nuts (from *Tall* palms) are needed for 1 ton of copra; copra contains 65-70% oil.

PESTS AND DISEASES

The most serious insect pests are the Rhinoceros beetle, *Oryctes rhinoceros*, the beetles of which burrow into the terminal bud, damaging the unopened leaves; the red palm weevil, *Rhynchophorus ferrugineus*, the larvae of which burrow into the trunk and kill the entire palm; and the leaf-eating caterpillar, *Nephantis serinopa*. A large number of *Lepidoptera* and other pests have also been recorded.

The serious diseases are bud rot, caused by *Phytophthora palmivora*, and several other fungal diseases. However, the greatest threat to coconut production are certain diseases of unknown aetiology such as the "root (wilt) disease" of Kerala, India; the lethal yellowing of Jamaica; Cadang-Cadang disease of the Philippines, etc.

AGROFORESTRY POTENTIAL

There is tremendous scope for intercropping in coconut stands. Intercropping of varying types and intensities are practised, especially in smallholder farming. Mixed plantings of coconuts and other perennials such as cacao and spice trees are common in India and Malaysia. Cattle under coconuts is popular in Sri Lanka and the Pacific islands.

MAJOR RESEARCH INSTITUTIONS AND REFERENCES

Central Plantation Crops Research Institute, Kasaragod, 670124, Kerala, India.
Coconut Research Institute, Bandirippuwa, Lunuwila, Sri Lanka.
L'Institut de Recherches pour les Huiles et Oléagineux (IRHO)
11, Square Petrarque, Paris 75016, France.

The Philippine Coconut Administration (PHILCOA), Elliptical Road, Quezon City, The Philippines.
See: Coconut Research Centres and Organizations for International Cooperation, Oléagineux 22 (1967), 241-244.

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Fig. 21. Multistorey crop combination of 25 year-old coconut palms, cacao, pepper and pineapple (Photo credit: CPCRI, Kasaragod, Kerala, India).

OILS AND FATS

GROUNDNUT

SCIENTIFIC NAME

Arachis hypogaea L.
Family *Leguminosae* - *Papilionoideae*
2n = 40

COMMON NAMES

Groundnut, peanut	(E)
Arachide	(F)
Cacahuete, mani	(Sp)

USES AND ECONOMIC IMPORTANCE

Groundnuts are the second largest source of vegetable oil for cooking (the largest being soya beans), and for the manufacture of vegetable ghee (vanaspati) and soap. The kernels are also eaten raw, sweetened, or roasted. The oil-cake is a high-protein livestock food or organic fertilizer (containing 7-8% N, 1.5% P_2O_5, and 1.2% K_2O). The plant stalks are used as cattle feed. Groundnut shell is used as fuel, and in the manufacture of coarse boards, cork substitutes, etc.

ORIGIN AND DISTRIBUTION

Groundnut is native to Brazil from where it was introduced into Asia and Africa in the 16th century. It is now cultivated in all tropical and subtropical countries. India, China, West African countries, Nigeria, the U.S.A., Brazil and Argentina are the major producing countries.

PLANT CHARACTERISTICS

Groundnut is a low-growing (15-60 cm high), erect or trailing, sparsely hairy annual herb. It has a well-developed tap-root with many laterals, usually with good nodulation. Branching of the stem is dimorphic with monopodial vegetative branches and reduced reproductive branches. The arrangement of these branches is of two distinct types: sequential and alternate. Sequential branching occurs in the true erect bunch forms. They have an upright main stem with 5-6 ascending monopodial branches from lower nodes (which may or may not have secondary branching), followed by reproductive branches from the next nodes and ending in a series of sterile branches. The alternate branching occurs in the true runner (prostrate) types and the less spreading (spreading bunch) types. In these, the main stem produces lateral monopodia, on which the first 2 axils produce secondary monopodia, followed by reproductive branches at the next 2 axils, then another pair of vegetative branches and so on with alternate pairs of vegetative and reproductive branches before the branch terminates in a series of sterile axes.

Leaves are spirally arranged with a 2/5 phyllotaxy, pinnate with 2 opposite pairs of obovate leaflets.

Flowers are borne on compressed spikes in the axils of foliage leaves, but never at the same node as vegetative branches, with more flowers in the lowest nodes.

Flowering occurs 4-6 weeks after planting with peak flowering in the next 4 weeks. Pollination (self-pollination) takes place within the closed keel before the flower opens; usually only one flower opens on one day on an inflorescence. The floral parts wither away 5-6 hours after opening of the flower. After fertilization, the meristems at the base of the ovary grow to a peg, grow downwards to the soil, penetrate the soil to a depth of 2-7 cm, and put the ovary at a horizontal position, where it swells rapidly. If the peg fails to reach the soil (at distances more than about 15 cm), the tip containing the ovary dies.

The fruit is an elongated pod containing 1-6 seeds; the dry and hard pericarp is reticulate, and the endocarp in mature fruit forms a thin papery lining.

The seeds are elongated and cylindrical or ovoid. The testa of the seeds varies in size, shape and colour in different cvs. Seeds have two massive cotyledons, but no endosperm.

There are several cultivars; the identifiable agronomic characteristics are (i) branching habit - sequential or alternate; (ii) habit - erect bunch, spreading bunch, or runner, (iii) size and shape of pod, (iv) number of seeds per pod, and (v) colour of testa after storage. The main cvs belong to the following sections:

Virginia: alternate branching, runners or spreading bunch types, long season forms or slightly indeterminate growth habit or weakly perennial, dark green foliage; seeds have a dormancy of 30-60 days; 2 seeded pods; testa colour is deep brown.

Spanish - Valencia: sequential branching, erect bunch form, main axis exceeds laterals in length, annual short-duration forms of 90-110 days duration, light-green foliage, no seed dormancy, pods 2-6-seeded, and wide range of kernel size and testa colour.

Many cvs are cultivated in different parts of the world. Improvement by breeding is difficult because the crop is inbred and crossing is difficult. Some high-yielding types have been developed in India.

ECOLOGY

Groundnut is cultivated in areas lying between the 40°S and N parallels of equator, up to about 1000 m elevation and receiving 50-125 cm annual rainfall, of which about 50 cm is received during the crop's growth. It is a warm season crop and dry weather is required for ripening and harvesting. It does not tolerate frost.

Groundnuts grow well in reasonably fertile, light, well-drained, friable soils that are well-supplied with calcium and moderate amounts of organic matter. They do not tolerate waterlogging.

PHYSIOLOGY AND COMPOSITION

Groundnuts require adequate but not excessive moisture during the period from flower formation to flowering; excessive rains prolong vegetative growth. They do not tolerate frost. They are usually grown in the open, but also intercropped with other crops and under thin stands of dense-canopied trees.

The oil content of the seed varies from 40 to 50%; the Spanish types contain more oil. The average composition of shelled nuts is protein 30.4%, fat 47.7%, carbohydrate 11.7%, fibre 2.5%, ash 2.3% and water 5.4%. The oil contains about 53% oleic acid and 24% linoleic acid. Groundnuts are rich in vitamin A and E and some of the B_2 group.

AGRONOMY

CROPPING SYSTEM Usually grown in rotation with cotton, tobacco, maize, millets, etc. Sorghum-groundnut-cotton is a very popular crop rotation in central parts of India.

LAND PREPARATION The crop may be planted on ridges or on the flat; the former reduces plant population but facilitates harvesting.

SOWING, SEED RATE The pods should be shelled just prior to sowing. Only well-formed seeds should be selected, and they should be treated with mercurial dressing as a prophylactic measure. Spacing and seed rate depend on growth habit, but usually closer spacing gives better yield. Sowing is done by hand in about 10 cm deep furrows and covered, or mechanically. For bunch types, 15 x 25 cm spacing with about 80 kg shelled seeds/ha is recommended, and for spreading types and runners, 30 x 60 cm spacing and about 40 kg seeds/ha. Though 250,000 plants/ha are desirable, the plant population is usually around 200,000/ha.

MANURING AND AFTERCARE In peasant farming the only manure applied is farmyard manure at the time of sowing, but the crop has been found to respond to fertilizers. Fertilizer recommendations for groundnuts in different States in India vary from 10-30 kg N, 20-60 kg P_2O_5 and 0-60 kg K_2O per hectare. Better results are often obtained if fertilizers are applied to the previous crops in rotation rather than directly to the groundnuts. The crop requires a good supply of calcium in the soil. It receives a hand weeding and one or two hoeings during the early stages of growth. But the soil should not be disturbed after the 'pegs' have commenced to form.

HARVESTING The crop attains maturity in 3½ months (bunch type) to 5 months (spreading type). When mature, the lower leaves turn yellow. Usually harvesting is done by pulling out, by hand. To make this easier, a light stirring of the soil or a light irrigation may be necessary for the spreading type. The pods are stripped from the vines after harvest, and dried in the sun.

YIELD

Yield varies from 1200-1500 kg/ha of unshelled pods for spreading types and from 800-1200 kg/ha for bunch types. But under good management, yields up to 3000 kg/ha are possible. The shelling percentage is 80 for the bunch types and 65-70 for the spreading types.

PESTS AND DISEASES

Tikka disease, caused by the fungus *Cercospora* spp., results in serious leaf spots and defoliation in most groundnuts-growing countries. Other fungal diseases are also common.

Rosette virus is the most serious disease in Africa, particularly in the wetter parts. Aphids *(Aphis laburni)*, and the red hairy caterpillar *Amsacta albistriga*, are the major pests in India, and the caterpillar *Anticarsia gemmatalis* is the common pest in the U.S.A.

AGROFORESTRY POTENTIAL

The crop is traditionally grown in the open, but is also inter-cropped with other agricultural species. However, it also grows under thin stands of light-canopied trees, as in West African countries, which shows its agroforestry potential; moreover, its short duration and leguminous nature are added advantages.

MAJOR RESEARCH INSTITUTIONS AND REFERENCES

Agricultural research institutions in the different provinces of northeast Brazil; Kwadaso Agricultural Experiment Station, Kumasi, Ghana; Central Research Institute for Agriculture, Padang, Indonesia; Agricultural Research Institute, Mogadiscio, Somalia; National Agricultural Research Centre, Bambey, Senegal; etc. are some of the research institutions in the developing countries.

Considerable research has been done on all aspects of cultivation of groundnuts; reports can be seen scattered in several journals dealing with tropical oilseed crops, notably Oléagineux, East African Agri & For. J., Empire J. Exp. Agri. (Exptl. Agric.), Indian Oilseeds J., Indian J. Agric. Sci., etc.

Fig. 22. Groundnut under *Acacia*, Senegal.

OILS AND FATS

OIL PALM

SCIENTIFIC NAME	*Elaeis guineensis* Jacq.
	Family *Palmae*
	2n = 32

COMMON NAMES	Oil palm	(E)
	Palmier à huile	(F)
	Palma de aceite	(Sp)

USES AND ECONOMIC IMPORTANCE

The three principal commercial products of oil palm are palm oil, palm kernel oil and palm kernel cake. Oil palm gives the highest yield of oil per unit land area of any plant. Palm oil is obtained from the fleshy mesocarp of the fruit, which contains 45-55% oil. It is used for food preparation and in the manufacture of soaps, etc.

Palm kernel oil is obtained from the kernel or endosperm, which contains about 50% oil. It is similar to coconut oil and has a high proportion of saturated fatty acids, especially lauric. The palm kernel cake obtained after extraction of oil from the kernels is an important livestock feed.

The leaves are sometimes used for thatching and the petioles and rachises for fencing.

ORIGIN AND DISTRIBUTION

The oil palm is believed to have originated in the tropical rain forest region of West Africa. Today it is cultivated in the equatorial tropics in West Africa, Southeast Asia and Central and South America. The major producing countries in West Africa are Nigeria, Sierra Leone, Ivory Coast, Dahomey and Zaire, and in Asia, Malaysia and Indonesia. New oil palm plantations are being established in Latin America, in Brazil, Colombia, Costa Rica, Ecuador, Honduras, Guatemala, Nicaragua, Panama, Mexico and Venezuela.

PLANT CHARACTERISTICS

An unbranched tree, 20-30 m high, which lives up to 200 years. The seedling radicle is replaced by adventitious primary roots, 8-10 mm in diameter, which extend either downwards or radially in a somewhat horizontal direction in the top 1 m of the soil. They produce secondary roots, 2-4 mm in diameter, which descend downwards in the soil. Tertiaries and quaternaries are also produced. Most of the roots are concentrated in the top 15 cm of the soil, mainly near the palm, but also at 1.5-2 m from the base. There are no root hairs; absorption seems to be through quaternaries which are not lignified.

The trunk is formed within 3-4 years after planting; it has a wide base; elongates at the rate of 25-50 cm per year; leaf bases are retained on the stem for several (about 12) years; stem diameter is usually 45-50 cm.

The crown consists of 40-50 opened leaves and a central spindle with 40-50 leaves in various stages of development. In fully-grown palms, the leaves are arranged in two sets of spirals, eight leaves in one direction and 13 in another. Usually about two leaves unfurl every month - more in young and less in old palms, and the leaves fall off about 2 years after unfurling. Mature leaves are simply pinnate bearing linear leaflets on each side of the leaf stalk. Leaflets linear, 250-300 per leaf and semi-xerophytic with thick cuticle.

An inflorescence is initiated in the axil of every leaf but some abort before emergence. In each inflorescence, either the male or the female remains rudimentary, so that either a male or a female inflorescence is produced; the proportion of female to total inflorescence is known as sex ratio; it depends on both genetic and environmental characters. Sex differentiation occurs about 10 months after inflorescence initiation, and anthesis takes place a further 2 years later. The male inflorescence is borne on a peduncle longer than that of the female, and contains long finger-like spikelets, each with 700-1200 closely packed small male flowers. The female inflorescence reaches a length of about 30 cm before opening. Female spikelets are thick and spiny; about 12-30 flowers on central spikelets and 12 or less in lower and upper ones. Hermaphrodite inflorescences are also produced occasionally. Pollination is almost exclusively by wind.

The fruits are ready for harvest 5-6 months after flowering. Fruit bunches are massive, nearly spherical, 10-90 kg with an average of 15-30 kg in weight, containing 500-4000 fruits per bunch, with an average of 1500, which constitute 65% by weight of the bunch. The number of bunches per palm depends on a number of factors.

The fruit is a sessile drupe, nearly spherical to ovoid, 2-5 cm long, 3-30 g in weight. Fruits in the inner part of the bunch are somewhat flattened and less pigmented. Exocarp is smooth and shiny; the oil-rich mesocarp or pulp, which constitutes 40-95% of the fruit is orange-coloured and contains 10-20% of longitudinal fibres. The fruit usually has one seed, but sometimes contains 2-3. The endocarp or shell around the seed constitutes 1-50% by weight of the fruit, is very hard, and dark brown with longitudinal fibres. The seed or kernel weighs 2-4 g and is 2 cm long or less.

VARIETIES AND CLASSIFICATION Strictly speaking, botanical cultivars do not occur; individual palms are very heterozygous. Based on the structure of the fruit, there are three types. *Dura* (DD) is the most abundant type in West Africa; the endocarp (shell) is 2-8 mm thick and constitutes 25-50% by weight of fruit. *Tenera* (Dd) has a thin (0.5-3 mm) shell, high (60-95%) mesocarp content and smaller kernels than *dura*. It has a higher sex ratio and more bunches than *dura*, but a lower mean bunch weight and lower fruit-to-bunch ratio. *Pisifera* is shell-less, and is predominantly sterile; the palm is of little commercial value, but has now attained importance in breeding commercial palms, using *pisifera* as the male parent.

Tenera is a monofactorial hybrid between *dura* and *pisifera*. Most commercial plantings are made with *tenera* palms produced by crossing *dura* with *pisifera*.

ECOLOGY

CLIMATE Oil palm grows best in areas with a mean maximum temperature of 30-32°C, a mean minimum of 21-24°C, and an average of at least five hours of sunshine per day throughout the year. This sets the limits of altitude and latitude at which it can be grown. It is grown in low-lying areas between 10°N and S latitudes, which receive an annual well-distributed rainfall of 200 cm or more. However, it can tolerate 2-4 months of dry period.

SOILS The palm grows on a wide range of tropical soils; soil moisture characteristics seem to be more important than nutrient supply. The adult palm can withstand occasional waterlogging, but frequently-waterlogged, extremely sandy, highly lateritic and stony or peaty soils should be avoided. Many of the soils used for the crop have pH 4-6, but it can be grown on soils with a wider range of pH.

PHYSIOLOGY AND COMPOSITION

Production physiology and effect of climatic factors on the crop's growth have been studied extensively. In general, oil palm is a light-loving plant or heliophile; shading palms of all ages reduces growth and net assimilation rate. Under good growing conditions in Malaysia, annual crop growth rates of 30-40 t dry matter per ha have been obtained.

The palm oil contains 39-52% oleic acid, 32-45% palmitic and 5-11% linoleic acid, thus giving a high content of unsaturated fatty acids. Palm oil is rich in carotene. Palm kernel oil contains 46-52% lauric acid, 14-17% myristic acid, and 13-19% oleic acid. Palm kernel cake contains approximately 11% water, 19% protein, 48% carbohydrate, 5% fat, and 13% fibre.

AGRONOMY

CROPPING SYSTEM The palms grow naturally in groves in West Africa and Brazil. Commercial plantations have also been established, mostly in cleared primary and secondary forests. In areas where it is feasible and economical to clear the undergrowth, food crops can be grown during the palm's early stages of growth. Mixed planting with other perennial crops and cattle grazing are also practised, though on a limited scale.

PROPAGATION Fully ripe seeds are selected, and their pulp is removed by retting for 10 days and then pounding with sand. Seeds are then dried in the shade for 1-2 days, after which they can be stored for up to one year in the ambient temperature. Heat treatment is necessary for germination, which can be done in boxes of fermenting vegetable matter or germinators. The seeds are soaked in water for 7 days with a daily change of water, then dried in the shade for 24 hours, and then tied in polythene bags and kept for 80 days at 39°C in the germinator. Then they are again soaked in water for 7 days, dried in the shade to evaporate the water on the surface and placed in polythene bags at the ambient temperature for germination. Seeds are examined occasionally and sprinkled with water. Germination starts in about three weeks and is completed in the next two weeks. Germinated seeds can be transported long distances in polythene bags.

NURSERY When the radicle and plumule are clearly differentiated, the seeds are planted in raised pre-nursery beds made of friable, well-drained soil, or in trays or baskets. Black polythene bags are preferred for ease in transportation. When the seedlings reach the 4-5-leaf stage (in 4-5 months),they are planted in a field nursery 75-90 cm apart, or in larger black polythene bags. Nurseries are manured with N, P, K and Mg.

FIELD PLANTING If planted in cleared forest areas, the undergrowth is seldom completely cleared; instead, an area of about 1 m radius around the planting holes is cleared of all vegetation. Usually 12-18-month-old seedlings are transplanted at a triangular spacing of 9 m between palms (and 7.6 m between rows) thus giving a density of 150 palms per hectare. Transplanting may be done at the beginning of rainy season.

AFTERCARE Porcupines and wild bores sometimes damage the young palms. On large plantations, leguminous cover crops such as

Calopogonium mucunoides Desv., *Centrosema pubescens* Benth. and *Pueraria phaseoloides* (Roxb.) are established. On small holdings, intercropping with food crops is practised.

MANURING Oil palm is a heavy feeder and adequate amounts of nutrients may be given to ensure good yields. Fertilizer recommendations vary considerably depending upon the soil conditions and yield level. Foliar analysis is used as a guide for determining the nutrient needs. General fertilizer schedules consist of about 1 kg N, 0.5 kg P_2O_5 and 2 kg K_2O per palm annually.

HARVESTING It is important to harvest bunches at the optimum stage of ripeness; under-ripe fruits have oil with a high fatty acid content. Initial bunches, produced when the palms are 3-4 years old, are often of poor quality and are discarded, the process being known as 'castration'. Bunches are harvested about once a week, with a steel chisel during the first few years, with an axe later, and with a curved knife attached to a long bamboo pole when the palms are older. Tall palms are also climbed with ladder or ropes. One man can harvest 100-150 bunches per day.

PROCESSING The fruits are removed from the bunches after the bunches are transported to the processing site. Indigenous methods for extraction of oil are practised in Nigeria; these include a hand-operated curb press. Improvements such as the hydraulic hand press have resulted in increases in efficiency of 75-85%. In Malaysia, large power-operated mills are used on large plantations of about 8000 ha. The steps involved are sterilization of bunches, stripping of bunches, digestion and mashing of fruit, extraction of mesocarp oil, clarification of the palm oil, separation of fibre from the nuts, nut-drying, grading and cracking of nuts, and separation and drying of the kernel. Importing countries stipulate a free fatty acid content of about 5%. To assure this, fruits when shipped must have FFA content of about 3%, because it increases in transit.

YIELD Estate yield in Africa varies from 7.5-15 tons of bunches per ha annually; in Malaysia it is 20-30 t, and sometimes up to 40 t/ha. With 15-20% recovery of oil from a bunch on a weight basis, yields well over 5 t palm oil per ha per annum are obtained.

PESTS AND DISEASES

Many pests of coconut such as the red palm weevil, *Rhynchophorus* spp., attack oil palm also. Several fungal diseases affect the seedlings and adult palms, causing leaf spots, basal and crown rotting, etc. Diseases of unknown aetiology and those caused by mineral deficiencies and imbalances are also common.

AGROFORESTRY POTENTIAL

The role of oil palm in agroforestry is as an overstorey species in the adult stages of the palm, and as a species with which other crops can be intercropped during the palm's early stages. Mixed plantings of other perennial species and cattle raising are also possible in adult plantations.

RESEARCH INSTITUTES AND REFERENCES

Considerable research has been done on oil palm both in West Africa, mainly by the Nigerian (formerly West African) Institute of Oil Palm Research and in Malaysia (Palm Oil Research Institute and Malaysian Agricultural Research and Development Institute), and a voluminous literature has been produced.

The Journal of the NIFOR (formerly J.West Afr. Inst. Oil Palm Res.) (since 1953) and the publications of the Incorporated Society of Planters, Kuala Lumpur, are the foremost periodicals. The most comprehensive book on oil palm is:

Hartley, C.W.S. 1977. The oil palm. 2nd ed., Longman, London.

Fig. 23. Vegetables with young oil palms, Malaysia.

RAPESEED - MUSTARD

SCIENTIFIC NAME AND COMMON NAMES

Several oil-seeds belonging to the family *Cruciferae* are grown in the Indian subcontinent, under the names rapeseed and mustard. The important ones are:

Brassica juncea (L.) Czern and Coss; 2n = 36; Mustard
B. campestris var. *toria* Duthie and Fuller; 2n = 20; Rapeseed
B. campestris var. *sarson* Prain; 2n = 20; Yellow sarson
B. campestris var. *dichotoma* Watt.; 2n = 20; Brown sarson

Colza - moutarde (F)
Colza - mostaza (Sp)

USES AND ECONOMIC IMPORTANCE

The seeds contain 30-48% edible oil, which is the most important cooking oil in India. The seed is used as a condiment and the oil for the preparation of pickles and as a flavouring agent for curries and vegetables. The oil cake is used as a cattle feed, and the young leaves and plants as green vegetables. The oil has only limited industrial use.

ORIGIN AND DISTRIBUTION

The Brassicas are believed to be natives of the Mediterranean region. They are widely cultivated in the subtropical regions and the higher altitude areas of the tropics. *B. juncea* is extensively cultivated from eastern Europe to China, and in Africa. Both *B. juncea* and *B. campestris* are important oil seed crops in India.

PLANT CHARACTERISTICS

A slender, erect, branched annual, up to 1 m high. The plant has a tap root with numerous laterals. The stem is slender and thicker at the base. Leaves alternate; lamina broad, ovate to rounded; petioles long. Inflorescence is terminal. Flowers open from the base of the inflorescence and proceed upwards. Flowers are bright yellow, 7-9 cm long in *B. juncea* and 2.5-5 cm long in *B. campestris*. Flowers are self-sterile. Fruits are slender, many-seeded, 2.5-5 cm long, dehiscing. The crop matures in 75-100 days. Several improved, high-yielding strains have been evolved in India.

ECOLOGY

The crop requires somewhat cool weather for satisfactory growth. In northern parts of India, it is sown in the autumn before the main winter (rabi) crop. In temperate regions, it is cultivated during summer. *B. campestris* var. *toria* is more susceptible to cold and frost, and is usually harvested in December. Water requirement of the crop is less than 500 mm. It can be grown in soils ranging from light loam to heavy loam, if rainfall and fertility are adequate. Waterlogged soils are unsuitable.

PHYSIOLOGY AND COMPOSITION

Day length is not critical for the plant, but it does not tolerate excessive heat, and is susceptible to drought. However, *B. campestris* often matures early enough to escape the drought.

Oil content is 40-45%, of which only 3-6% is saturated fatty acids. Rapeseed oil contains 20-45% erucic acid which can serve as a substitute for -lein in flotation agents.

AGRONOMY

Rapeseed and mustard are usually grown mixed with other winter crops or in sole stands as a catch crop in rotations between early varieties of summer crops and late varieties of winter crops. The seeds are either broadcast or sown in lines about 50 cm apart. After germination, the plants are thinned down to a stand of 10-15 cm between plants. The seed rate is about 6 kg/ha for a broadcast crop. The crop is weeded and hoed twice; it responds well to manuring; for good yields, 30-60 kg N and 10-30 kg P_2O_5/ha are recommended as a basal application. Harvesting is done when the crop begins to turn yellow, about 90 days after sowing for rapeseed and 120-160 days for sarson. The whole plant is cut and stacked; threshing is usually done by beating with sticks or pounding by animals. After winnowing, the seed is stored in gunny bags.

YIELD

Average yield of seeds is about 500 kg/ha; under good conditions, yields over 1000 kg/ha are obtained. Oil is extracted either by pressure or with solvents.

PESTS AND DISEASES

Rapeseed and mustard are attacked by a number of insects, the most important being the mustard aphid, *Lipaphis erysioni*, and the mustard saw-fly, *Athalia proxima*. Alternaria blight, *Alternaria brassicae*, is the most destructive disease.

AGROFORESTRY POTENTIAL

This short-duration crop is relatively easy to manage and can be grown with residual soil moisture after the rains. It can be grown as a catch crop in plantations after pruning and thinning.

RESEARCH INSTITUTIONS AND REFERENCES

Several agricultural Universities in India have research projects on rapeseed and mustard. The Department of Agriculture of the Government of India has a directorate for oil seeds development.

Indian Oilseeds Journal published since 1956, Indian Farming, The Indian Journal of Agricultural Sciences, and Oléagineux (Paris) publish articles and research findings on these crops.

OILS AND FATS

SESAME

SCIENTIFIC NAME	*Sesamum indicum* L. syn. *Sesamum orientale* L. Family *Pedaliaceae* 2n = 26
COMMON NAMES	Sesame, gingelly, til (E) Sesame (F) Sésamo (Sp)

USES AND ECONOMIC IMPORTANCE

The edible seeds of sesame are the source of sesame oil, a semi-drying oil used as a substitute for olive oil in salads, and for cooking. The oil-cake is rich in protein and is a good cattle feed. Seeds are used for various culinary purposes and the young leaves are used as a soup vegetable. Also used in native medicines. Dried stems are burnt as fuel.

ORIGIN AND DISTRIBUTION

Sesame was first cultivated in Africa and was taken at a very early date to India where a secondary centre of diversity developed. Now India has about 2-3 million hectares under sesame, which is about 50% of the world area. China, Burma, Sudan, Mexico, Pakistan, Turkey, Venezuela, Uganda, Tanzania and Nigeria are other countries where sesame is now cultivated.

PLANT CHARACTERISTICS

Sesame is an erect, branched or unbranched annual herb, 0.8-1.8 m tall, maturing in 90-180 days. It has a long (90 cm) tap root and a dense surface mat of feeding roots. Leaves are hairy on both sides and variable; the lower leaves are opposite, broad, and palmately lobed, and the upper leaves are alternate, narrow and lanceolate. Flowers are small; are white, pink, or purple and produced in the axils of upper leaves, 1-3 per axil; mostly self-pollinated, but about 5% cross-pollinated.

The fruit is a capsule, 1 x 3 cm; it bursts open through 2 apical pores when mature, causing considerable loss of the crop.

Seeds are small, 3 x 1.5 mm, ovate, about 300 seeds to one gram; seeds white or black.

There are a large number of cvs and races of sesame, differing in duration, season of planting, degree of branching, number of flowers per axil, etc. High-yielding hybrids have also been evolved.

Most cvs mature in 3-4½ months after sowing.

ECOLOGY

Grown in hot, dry areas, from sea level up to 1000 m altitude, with an annual rainfall of 50-120 cm. Sesame needs 40-50 cm rain during its growing season; adequate moisture is necessary during the early part of growth, but heavy rains after sowing are a disadvantage. Does not tolerate waterlogging; moderately drought resistant after establishment.

Not very exacting in soil requirement; does well on sandy loams; can grow reasonably well on poor soils.

PHYSIOLOGY AND COMPOSITION

Most cvs of sesame are sensitive to photoperiod; both short- and long-day forms occur. Sesame has poor ability to compete with weeds in the early stages of growth.

Seeds contain 45-55% oil and 19-25% protein. Oil is of high quality, odourless, does not become rancid; contains unsaturated fatty acids - mainly oleic and linoleic, about 40% each.

AGRONOMY

CROPPING SYSTEM Usually grown as a rain-fed crop in pure stand. Also grown as a 'catch crop' as the first or the last crop of arable seasons and mixed with other crops such as pigeon pea, millets, etc.

LAND PREPARATION A rough seed-bed is preferred so that even if rains occur immediately after sowing, the crust or cap formation is minimum.

PROPAGATION By seeds.

SOWING Seeds are usually broadcast at the rate of 5-8 kg/ha. Often mixed with soil before sowing in order to achieve an even spread. If sown in lines, or if thinning is done, the optimum plant population is 170,000-200,000/ha in rows about 25 cm apart.

AFTERCARE Plants are very slow-growing and intolerant of weeds during early stages, when the plants should be weeded and thinned.

NUTRITION Usually not fertilized, but fertilizer experiments in different parts of India and other countries have shown good response to N and K; 30-50 kg N, 10-20 kg P_2O_5 and 30-40 kg K_2O per hectare are recommended in different countries.

HARVESTING Dehiscence and non-uniform ripening of capsules are two problems; so plants are cut or uprooted with minimum shaking when lower capsules are dry, and the plants are stacked in the field to facilitate ripening of upper capsules. Sometimes the cut plants are also dried in bunches hanging downwards on racks for 1-2 weeks, so that the dry seeds fall on a mat kept below.

YIELD

Peasant yields vary from 250 to 500 kg/ha; with improved husbandry, yields are double those amounts. High yields of up to 2000 kg/ha are reported from Venezuela and Mexico.

PESTS AND DISEASES

Leafspots caused by *Pseudomonas sesami* and *Cercospora sesami* are the serious diseases, whereas the webworm *Antigastra catalaunalis* defoliates the plants.

AGROFORESTRY POTENTIAL

Sesame is a good crop for agroforestry because of its drought resistance, ease of management, adaptability to poor soils, and suitability for intercropping.

IMPORTANT REFERENCES

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Fig. 24. Sesame and *Acacia senegal* in sandy soil of the Sudan (Photo credit: A.G. Seif-el-Din).

Fig. 25. Soyabean intercropped with 18 month-old budgrafted rubber trees (Photo credit: Rubber Research Institute of Malaysia).

OILS AND FATS

SOYA BEAN

SCIENTIFIC NAME	*Glycine max* (L.) Merr. Family *Leguminosae, Papilionoideae* 2n = 40

COMMON NAMES	Soya bean, soybean	(E)
	Soja, soya	(F)
	Soja, frijol de soya	(Sp)

USES AND ECONOMIC IMPORTANCE

Soya bean is the most important plant source of oil and protein. Soya sauce, which is made from mature fermented beans, is one of the principal sauces of East Asia; there soya bean is also an important food crop, both unripe (as a vegetable) and dried seeds being eaten. The oil obtained from the seed is a semi-drying oil and is used for dietary purposes in the Far East and in the U.S.A. Oil is also used for industrial purposes. Soya meal, which is the residue after the extraction of oil, is a protein-rich feed for livestock. Soya flour prepared from the whole beans is used in bakery and other food products.

ORIGIN AND DISTRIBUTION

Soya bean has been in cultivation in China and the Eastern countries since very ancient times. The major producers at present are the U.S.A. and China. It is also cultivated in other areas of subtropics and tropics where suitable ecological conditions exist. However in many parts of Africa and in India, the local people find the beans difficult to cook and unpalatable.

PLANT CHARACTERISTICS

A bushy, erect, pubescent, annual, 40 to 180 cm tall, with small grey hairs on stem, leaves, calyx and pod. Some cvs are prostrate with a tendency for twining. Cultivars with determinate and indeterminate growth habits occur.

There is a well-developed tap root descending as deep as 150 cm. Most of the roots are in the 30-60 cm layer of the soil.

Nodules are usually small and spherical, and sometimes lobed. The main stem branches into 3-5 laterals depending upon the cv. and density of planting. Leaves are alternate, usually trifoliate with long narrow cylindrical petioles and ovate to lanceolate leaflets; pale green in colour. Flowers are small, borne on short, clustered axillary or terminal (in determinate types) racemes, with 3-15 flowers in axillary and up to 30 in terminal racemes. Usually self-pollinated; 20-80% of flowers drop off without forming pods. Pods are borne in clusters on short stalks in groups of 3-15; they are hairy and slightly curved; contain 1-5 seeds. Seeds are mostly globose, testa varies in colour - yellow, green, brown, black or mottled; 100 seeds weigh 5-40 g, usually 10-20 g.

Length of growth period depends upon the cv. and day length of the growing season; but usually the crop matures in 75-200 days.

Soya bean is a crop that has received considerable research and therefore many improvements have been made. Introduction of cvs, selection, hybridization, and irradiation are the common techniques adopted with the objectives of increased yield, time to maturity, freedom from lodging and shattering, oil content, testa colour, disease resistance, fodder quality, etc.

ECOLOGY

CLIMATE Climate requirements of the soya bean are somewhat similar to those of maize; it is grown mainly in areas where the summer is hot and humid. However, it does not withstand extreme summers and winters. It is less susceptible to frost than cowpea. Soya bean is a subtropical plant, but its cultivation at a particular latitude is decided on the basis of the time taken for maturity. Nine maturity groups from 0 to VIII are recognized in the U.S.A., each having a narrow range of latitude.

SOIL Soya bean grows on a wide range of soils, but sandy or clay loams and alluviums with good fertility are the best. When taking up cultivation in a new area, inoculation with the bacterial culture of *Rhizobium japonicum* is desirable.

PHYSIOLOGY AND COMPOSITION

Soya bean is a short-day plant and is very photo-sensitive. It will remain vegetative almost indefinitely if the days are long enough, and will flower in less than a month from sowing if the days are short. Most cvs have a narrow range in which they will mature properly. For best yields, soya beans require full exposure to sunlight; with shade, the prostrate and twining tendency increases.

The composition of soya beans varies with the cv. and the soil and climatic conditions. Cultivars with black seeds are richer in protein than those with yellow seeds; but yellow-seeded cvs are richer in oil than black-seeded ones. The dried seed contains 5-9.4% water, 29-50% protein, 13-24% fat, 14-24% carbohydrate, 3-6% fibre and 3-6% ash. Solvent-extracted soya meal contains about 45% protein and 30% carbohydrate. Soya bean oil contains about 51% linoleic acid, 30% oleic acid and 6.5% linolenic acid.

AGRONOMY

Soya bean is usually grown as a sole crop, but it is also interplanted with other field crops like maize or in rotation with them. It is propagated by seed. It requires a well-prepared, firm seedbed. The seeds are sown 3-5 cm deep; the spacing depends upon the cv. and the purpose (grain or fodder) for which it is grown. Row spacing in the U.S.A. varies from 0.5-1.0 m, with plant-to-plant distance of 5-10 cm. In the Far East, the spacing along the rows is 10-15 cm, and the row spacing is 60-90 cm. Seed rate varies from 40-60 kg/ha. Soya bean production is almost fully mechanized in the U.S.A.

The crop responds well to phosphate and potash fertilizers and to calcium in calcium-deficient soils. The usual recommendation is 30-60 kg P_2O_5 and 50-80 kg K_2O/ha. Intercultivation, mainly for removing weeds, is done until the plants flower.

Harvesting is done by cutting the plants at ground level before the pods shatter; they are dried for sometime before threshing; when grown for hay, the plants are cut when the pods are well-formed but before the leaves are shed.

YIELD

Average yield in the U.S.A. is 1500-2500 kg/ha; in the Far East, yields are lower. The hay crop yields up to 5 t hay/ha.

PESTS AND DISEASES

Though it is relatively free from insect pests, podborers (*Laspeyresia glycinivorella* and *Etiella zinckerella*) sometimes damage the crop. The commonest diseases are bacterial blight caused by *Pseudomonas* spp. and *Xanthomonas* spp. and fungal leaf spots caused by *Cercospora* spp.

AGROFORESTRY POTENTIAL

Soya beans contain a higher percentage of protein than any other pulse and the plant is relatively drought-tolerant and easy to manage. It gives a fair crop even under partial shade.

RESEARCH INSTITUTIONS AND REFERENCES

The U.S.A., which is the leading producer of soya bean, is also the leading country in research on the crop: most agricultural experimental stations there have research programmes on soya bean. Most of the developing countries in the tropics also have strong soya bean research and development programmes.

Oléagineux, Indian Oil Seeds Journal, Indian Farming, Experimental Agriculture and others publish research results on soya bean from tropical regions.

BEVERAGES

CACAO

SCIENTIFIC NAME	*Theobroma cacao* L. Family *Sterculiaceae* 2n = 20
COMMON NAMES	Cacao or cocoa (E) Cacao, cacaotier (F) Cacao, cacaotero (Sp)

USES AND ECONOMIC IMPORTANCE

The word 'cacao' is used for the tree and its parts and 'cocoa' for the products of manufacture. Cocoa is an important beverage and is prepared from cacao beans. The shells of the pods are used as cattle feed or manure.

ORIGIN AND DISTRIBUTION

Its origin was in South America on the eastern equatorial slopes of the Andes. At present, West Africa (mainly Ghana, Nigeria, Ivory Coast and Cameroon) and South America (mainly Brazil and Ecuador) are the major cocoa producers. It is also cultivated in Asian countries (Malaysia, India, New Guinea) and the West Indies. Though cocoa is produced by a comparatively few tropical countries, the product is consumed mainly in temperate countries.

PLANT CHARACTERISTICS

Cacao is a small tree, 6-8 m tall, usually grown as an understorey species.

The tap root, which goes straight to 2 m depth, depending upon soil conditions and depth to the water table, gives rise to secondary roots up to 20 cm depth, and also from the tip of the tap root. The secondary roots near the soil surface grow laterally in the humic layer and produce a dense mat of feeding roots, which results in about 80% of roots being present within about 15 cm of the top soil. The secondary roots from the tip of the tap root may also grow towards the surface mat of roots.

The tree has a dimorphic branching habit. The main (single) stem of the seedling breaks up at 1-1.5 m height into the so-called jorquette, producing 3-5 lateral (plagiotropic) fan branches which may be almost horizontal. An axillary bud just below the jorquette produces an orthotropic branch called chupon which elongates and repeats the growth pattern of jorquette and tiers of fan branches. The number of tiers retained on the tree depends on the plantation practices.

Leaves are large, simple, dark-green when mature, 12-60 x 4-20 cm, those in the middle of the tree, where they receive less light, being largest. Leaves are produced in flushes on fan branches, the frequency of flushing being higher with high temperature or defective nutrition. In healthy trees, new flushes appear 2-4 times a year and the leaves persist through 2 further flushes, after which they drop off.

Cacao is cauliflorous, producing flowers on older leafless wood of the main stem and fan branches. Flowers originate from the "cushions" formed by the broadening of shortened, minute branches arising from the axillary bud of an ordinary leaf. One cushion produces about 50 flowers in one season. The inflorescence is a much-compressed cyme with greatly reduced branches. Flowers are hermaphrodite, and whitish or reddish.

Pollination takes place in the first 2-3 hours after dawn, but during the peak flowering season, only 2-5 of the flowers are pollinated and only a few of them set seed. It is estimated that only one in every 500 flowers matures to a ripe fruit. Fruit set in cacao is complicated by self- and cross- incompatibility. Self-incompatible clones are usually shown themselves to be cross-incompatible, but are cross-compatible with self-compatible trees. The site of incompatibility is in the embryo sac and not in the stigma and the style, and is genetically controlled. The main pollinating agents are the midges.

The fruit is a drupe, but is commonly called a pod. It is variable in size, 10-30 cm long, nearly spherical to cylindrical in shape. Young pods are green, purple or white and turn colour, upon ripening, to green, yellow and red or purple.

Pericarp (husk) is usually thick and fleshy. The seeds are usually called beans, and one pod contains an average of 20-60 seeds, usually arranged in 5 rows. Seeds vary in size, 2-4 x 1-2 cm, and in shape from ovoid to elliptic. Seeds constitute 25% by weight of mature fruit; 600-1000 seeds per kg of fermented beans.

VARIETIES The cultivated and wild cacao are divided into 3 main groups based on the Venezuelan trade names.

CRIOLLO Pods yellow or red when ripe, deeply furrowed, usually conspicuously pointed. The pod compresses when pressed in the hand. This group gives cocoa of the highest quality, lacking any astringent characteristics. Yields are comparatively low; beans ferment quickly; only small quantities are now available on the world market. Can be sub-divided into Central American Criollo and Venezuelan Criollo.

FORASTERO Unripe pods are green or whitish, turning yellow when ripe, surface smooth and inconspicuously furrowed; pod walls relatively thick; usually gives an astringent product. Trees hardier, more vigorous and higher-yielding than Criollo types. This group now supplies the bulk of world's cocoa.

TRINITARIO Hybrids between Criollo and Amazonian Forastero, occurring in Trinidad: very heterogeneous and exhibiting a wide range of characters such as colour and shape of pods, shape and pigmentation of cotyledons, etc. Best clones combine the vigour of Amazonian Forastero and the quality of Criollo. It is of great importance in breeding, and in the trade it is called 'fine'.

ECOLOGY

CLIMATE Cacao is a typical tropical crop with somewhat exacting climatic requirements. Areas of tropical evergreen rain-forest and semi-evergreen rain-forest are the most suitable ecological zones for cacao. The optimum temperature range is 21-32°C with a range of fluctuation not greater than 9°C. This exacting requirement precludes cacao being grown commercially beyond the 15° parallels north and south of the equator and at altitudes higher than 650 m within the tropical zone. Potential evapotranspiration within the cacao belt is between 100 and 125 mm per month, which necessitates a well-distributed annual rainfall exceeding 1250 mm, without drought periods longer than 3 months.

SOIL Cacao has rather exacting soil requirements also; it requires a deep (at least 1.5 m, but deeper in sandy soils), well-drained, well-structured, moisture-retaining soil with a high nutrient and organic matter content. The optimum pH of the soil for cacao growing is around 6.5. The best cacao soils in West Africa are derived from igneous rocks, while those in Trinidad are formed from marine sediments containing calcium carbonate and are rich in potassium and phosphorus.

PHYSIOLOGY AND COMPOSITION

In its natural habitat, cacao survives in dense shade but it can survive considerable exposure. During the early years of growth, shade is provided; seedlings grow best under about 25% full sunlight, which is subsequently increased to about 50%. Later, self-shading occurs and under optimal conditions of other environmental and soil factors, best growth and production occur under high light intensities. However, it is a usual practice to provide permanent shade from tall-growing trees. Flowering and leaf-flushing do not seem to be affected by photoperiod.

Oven-dried fresh cocoa kernels contain 7.7% starch, 1.8% sugars, 54% fat, 14.8% protein and 2.3% theobromine, whereas dried cocoa powder contains 22.2% starch, 4.3% sugars, 26.5% fat, 22.2% protein and 1.3% theobromine.

AGRONOMY

CROPPING SYSTEM Cacao is usually planted as an understorey crop after selectively thinning the original forest, or along with other economic trees which may be planted before or the same time as cacao. However, under very favourable conditions and with fertilizers, cacao can be grown without shade.

PROPAGATION Propagated commonly by seed, but vegetative propagation is also possible. Seeds may be sown at stake (at the rate of 3 per hole to be thinned later to one plant), or seedlings may be grown in a nursery, either in nursery beds or in baskets or polythene bags. Adequate shade may be provided in all these cases; the intensity of shade can be reduced as the seedlings become older.

Seeds germinate immediately on attaining maturity and are viable for only a short time. Germination may take place in the pod. Seeds may be sown shallow (3-5 cm deep). Germination is epigeal.

Propagation by grafting, layering and cutting is also possible and practised. Various types of propagators are available for inducing rooting in the cuttings.

LAND PREPARATION AND PLANTING Forest areas are selectively thinned and planting holes are dug about 3.5 x 3.5 m apart. In completely cleaned areas, shade plants are also planted. The planting holes are filled with organic matter and one year-old seedlings are transplanted. The spacing varies considerably depending upon environmental conditions, cv., etc. Closer spacing gives better yields in early years, but yields tend to even out in later years.

AFTERCARE Hand-weeding round the seedlings, gap filling, removal of ground shade in the 3rd year, regulation of overhead shade (initially 50%, to be reduced subsequently), watering and pruning are the main operations. The objective of pruning is to allow the development of a desirable framework (inverted cone) and canopy. Unwanted chupons are removed and growth is controlled at the first or second jorquette. Sometimes lower jorquettes are removed to facilitate movement on the farm. Plants propagated by cuttings are allowed to form 3-4 branches at the base, or a chupon is allowed to come up from ground level and the first fan branches then removed.

MANURING Cacao is self-manured (by fallen leaves), especially when grown under shade. However, when grown without shade, the plant responds very well to manuring, especially to N. Consequently, fertilizer practices vary considerably, but an annual application of 200 kg urea (90 kg N), 100 kg triple superphosphate (47 kg P_2O_5) and 400 kg potassium sulphate (200 kg K_2O)

per hectare can maintain yields around 2000 kg dry cocoa per ha in unshaded high-yielding cacao.

HARVESTING Bearing commences 2-3 years after planting and full bearing is attained in 6-7 years; the yield declines after 30 years. Pods are produced throughout the year, but usually there are one or two main harvesting seasons per year. Ripe pods assume distinctive colours and the seeds rattle inside. The pods are cut off with a sharp knife, care being taken not to damage the flower-bearing cushion.

FERMENTING The beans should be fermented to get the characteristic cocoa flavour and this should be done soon after harvesting to prevent germination and spoilage of beans. During fermentation, the mucilage around the seeds is removed, the precursor of the chocolate flavour is produced, and the astringency disappears. Cacao is usually fermented in heaps or baskets or wooden sweat boxes with provisions for aeration and free drainage of the sweatings.

The harvested pods are cut open to collect the beans and beans are fermented for 6-7 days. Criollo takes less time for fermentation than Forastero.

The fermented beans are spread on mats, trays or drying floors and dried in the sun for about 7 days, during which the moisture content is reduced from about 50% to 6%. During fermentation, the beans lose about 60% of weight. The dried beans are 'polished' by rubbing one against the other, either mechanically or with the feet.

YIELD

Yields vary considerably. On an average, 20-30 pods yield one kg of dried beans. Peasant yields are about 300 kg/ha dry beans for unselected plantings and about 800 kg/ha for selected ones. With high-yielding types, good management and fertilizers, yields as high as 3000 kg/ha are obtained.

PESTS AND DISEASES

Black pod disease, caused by *Phytophthora palmivora;* witches' broom, *Marasmius perniciosus,* which causes proliferation of branching with broom effect; and the swollen shoot virus, transmitted by mealy bugs, which causes the development of swollen shoots and branches and the death of the tree, are the major diseases. Cherelle wilt is a natural physiologic mechanism by which the immature pods shrivel and drop off so that only a limited number of pods, depending upon the food reserves, are brought to maturity; but sometimes it assumes pathogenic proportions and is aggravated by adverse environmental conditions and pathogenic organisms. Deficiency of various mineral nutrients also causes different disorders.

Capsids are the most important insect pests, of which *Distantiella theobroma* and *Sahlbergella singularis* are the most damaging, and they cause blast, persistent but weak flushing, etc.

AGROFORESTRY POTENTIAL

In areas where cacao can be grown (from the point of view of climatic and soil factors), this crop is one of the most promising and remunerative agroforestry species. However, it needs constant and painstaking managerial attention.

RESEARCH INSTITUTIONS AND REFERENCES

Considerable research has been done on cacao, the more prominent institutions being the Cocoa Research Institute, Tafao, Ghana, and the Cacao Research Centre at Bahia, Brazil.

Notable references are:

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Fig. 26a. Cacao under rubber in the Cameroun (Photo credit: Royal Tropical Institute, Amsterdam).

Fig. 26b. Cacao under *Deguelia* and *Ormocarpum glabrum* (Photo credit: Royal Tropical Institute, Amsterdam).

BEVERAGES

COFFEE

SCIENTIFIC NAME AND COMMON NAMES

Coffea arabica L. (2n = 44) Arabica coffee
Coffea canephora Pierre (2n = 22) Robusta coffee
(syn. *C. robusta* Linden)
Coffea liberica Bull (2n= 22) Liberica coffee
Family: *Rubiaceae*

Café (F)
Café (Sp)

USES AND ECONOMIC IMPORTANCE

Coffee and tea are the most popular beverages in the world; the dried and roasted coffee beans (seeds) are ground and brewed to make the beverage. Coffee is one of the most important and valuable commodities in international world trade. About 90% of the world's coffee is produced from *C. arabica*, 9% from *C. robusta* and 1% from *C. liberica* and other species.

The secondary uses include coffee pulp and parchment, which are used as manures and mulching materials.

ORIGIN AND DISTRIBUTION

C. arabica is a native of the Ethiopian highlands, *C. canephora* of the equatorial forests of Africa from the west coast to Uganda, and *C. liberica* of Liberia. Coffee is now produced in almost all tropical countries in Asia, Africa and Latin America. It is an important crop in many Latin American and East African countries. The U.S.A. and West European countries import coffee in large quantities.

PLANT CHARACTERISTICS

A robust, glabrous, evergreen shrub or small tree; arabica coffee grows to about 5 m height and robusta to 10 m. The root system consists of a short, stout tap root with laterals that grow vertically to about 2 m depth. The root system is superficial, usually confined to the top 60 cm soil.

Stems have dimorphic branching with a central upright orthotropic stem with plagiotropic fruiting or primary branches arising on the opposite side of each node in succession from the base upwards. In each leaf axil there are two buds, one above the other. Usually only the upper one develops into a primary. But when the main stem is damaged or topped, the lower axillary bud grows under the primary branch to produce an upright orthotropic vegetative shoot called a sucker or water shoot. Bending the main axis also stimulates production of suckers from several axes.

There are six buds in the leaf axils of primary branches, the one distal from the petiole being the largest and the oldest. Any or all of these buds may develop into inflorescences or secondary plagiotropic vegetative shoots; usually the first 3-4 buds develop into inflorescences. The sub-laterals (secondaries) can produce tertiary fruiting branches.

Leaves are opposite, dark green when mature, elliptical with a prominent acuminate tip; lamina is 10-15 x 6 cm in arabica and 15-30 x 5-10 cm in robusta.

Inflorescence, produced from 3-4 buds in the leaf axils of plagiotropic branches, consists of four flowers in two alternate pairs. Flowers are fragrant and white, and borne in clusters of 2-20 per axil. Flowering usually occurs in a flush and is stimulated by the onset of rains after a dry period. Flowers remain open for two days. Arabica coffee is self-fertile and usually self-pollinated; about 40% of flowers set fruits. But robusta coffee is self-sterile due to the failure of formation and growth of the pollen tube. Pollination is by wind and insects; usually 40% of flowers set fruits. The fruit is a berry, containing two beans, each enclosed in a tough membrane called parchment. Closely adhering to each bean is the very thin testa called silver skin. After removal of the silver skin, the dried beans become the coffee beans of commerce.

VARIETIES, CULTIVARS Arabica coffee has two botanical varieties: *C. arabica* var. *arabica* - it is vigorous; it grows quickly into a sturdy tree if not topped; it produces the bulk of the world's coffee. *C. arabica* var. *bourbon* is a more slender tree if not topped; it is slightly higher-yielding than var. *arabica* About 30 mutants of arabica coffee have been recognized. In addition, there are several best-known cultivars. A considerable amount of breeding and improvement work has been done. There are different types and forms of robusta coffee also, but their classification and re-identification are difficult because the species is self-sterile and it crosses readily. Upright and spreading forms are the two popular forms of robusta coffee.

ECOLOGY

CLIMATE The ideal growing conditions for arabica coffee are found on the equator at approximately 1500-1800 m, with 15-24°C temperatures, an annual rainfall of 1800 mm well distributed during 9-10 months and a dry period for the remaining 2-3 months. The altitude at which coffee is grown depends upon the distance from the equator; on Mount Kilimanjaro in Tanzania, it is 1200-1600 m; in Kenya 1500-1700 m; in Mexico 900 m; and in Parana, Brazil at latitude of 24°S, it is grown at sea-level.

At temperatures above the optimum, forced rapid growth, early and over-bearing, die-back etc. will result, whereas too cold a temperature causes excessive secondary and tertiary vegetative branches, and stunted growth. In areas with lower than optimum rainfall, the crop may be irrigated.

The crop is killed by frost. Early plantings were as an under-storey crop in forest plantations or under shade trees. But, as in cacao, where growing conditions are ideal, coffee yields best in the open.

Robusta coffee is suited to warmer conditions, and shows a wide range of adaptability. It is grown from sea level to 1500 m, but the optimum altitude is 300-600 m. Optimum temperature is 20-32°C, and optimum rainfall about 170 cm per year, with a dry spell for favouring flower initiation.

SOILS Coffee requires a well-drained and well-aerated soil; medium loams are ideal; heavy loams and clays are unsuitable. Being evergreen, coffee requires sub-soil moisture at all times, but the surface feeding roots require a drier period for part of the year to slow down vegetative growth and initiate flower buds. For best growth, the ideal pH is 6.0 to 6.5; but plants grow well even under more acidic conditions if there is an adequate supply of calcium and other nutrients.

PHYSIOLOGY AND COMPOSITION

The physiology of flowering in coffee, as mentioned earlier, is related to water stress; moisture stress is required to initiate flower buds, but they remain dormant until wetting breaks the dormancy. Dormancy can also be broken by gibberellic acid sprays. Phytotron studies have shown that coffee is a short-day plant; more flower buds are initiated at 8-to 10-h photoperiod than at a 12-to 13-h period.

Coffee is killed by hot temperatures as well as by frost. It does not withstand waterlogging. Much coffee is still grown under shade.

Raw dried coffee beans contain approximately 12% water, 13% protein, 12% fat, 9% sugar, 1-1.5% caffeine, 35% cellulose and carbohydrates and 10-14% water-soluble substances.

AGRONOMY

CROPPING SYSTEM Contrary to popular belief, coffee is predominantly a smallholder's crop. It is usually grown mixed with bananas in the Kilimanjaro region, and with shade trees like *Grevillea robusta*, *Albizia* spp., *Erythrina* spp., etc. During the early stages of growth, coffee is intercropped with beans, groundnuts, etc.

PROPAGATION Commercial propagation is by seed; seeds should be selected from high-yielding, progeny-tested trees. Vegetative propagation (by budding, grafting and soft-wood cutting) is possible, but it seems to have little advantages, except in breeding work and top-working.

NURSERY Seedlings are raised in nurseries on level ground, near a water source, and with deep fertile loams. The beds are usually raised 60 cm from the ground, 1.2 m wide and of convenient length. Seeds are hand-pulped; light beans that float in water and large ones are rejected; after a floating test seeds are dried in the shade until they contain 15-18% moisture and then sown in the nursery beds about 1 cm deep. Shade is provided; also occasional watering as necessary. After germination in about 4-8 weeks, the seedlings at the cotyledon stage are transplanted at 15-25 cm distance from each other. Sometimes the seeds are sown at this distance to avoid transplanting in the nursery. Seedlings are also raised in polythene bags and similar containers.

FIELD PLANTING The field is prepared at least a few months before planting by clearing the area of weeds (such as couch grass, *Digitaria scalarum*) and digging the planting holes about 60 cm deep and wide. The usual spacing is 2.7 m x 2.7 m or 3.0 x 2.4 m (to improve access between the rows).

Triangular and hedge systems of planting are also recommended. Transplanting should be done early in the rains. When used, shade trees should be quick-growing, tall, not very brittle and easily breakable, long-lived, deep-rooted and preferably leguminous species. It is advantageous to plant them from large cuttings. They should be established before planting coffee. In Brazil, when coffee is planted on virgin soils after removal of forests, direct seeding is done in the field with 10-12 seeds sown in each hole (3-3.5 m apart), and thinned down to 3-4 plants per hole.

AFTERCARE Cover crops are not popular in coffee plantations, but they are better than weeds. Weeding should be done by inter-cultivation, slashing or weedicides. Mulching is found beneficial, especially in areas with low and erratic rainfall, and it suppresses weed growth. Dry grasses, especially *Pennisetum purpureum*, banana trash, etc. are spread about 10 cm thick, usually in alternate rows, before the onset of rain. Dry grass, however, presents a fire hazard. Repeated mulching with grasses and other bulky materials may cause nutritional disorders for coffee.

PRUNING This is an essential operation in the management of coffee to control the height and shape of the tree and to maintain a correct balance between vegetative and reproductive growth. Pruning is done to induce the growth of fruiting branches on which the following season's crop will be borne. It consists of topping the main stem at a desired height, removing weak, dead or surplus branches, restricting the growth of the primary branches to the desired level, and reducing the number of fruiting branches. There are two main systems of pruning - single-stem pruning and multiple-stem pruning. Single-stem pruning aims at establishing a permanent framework of strong primary branches. It consists of retaining the original seedling stem and keeping it topped at about 2 m height, removal of all suckers, and thinning of secondary fruiting branches. It is also done by capping the main stem at knee-, waist-and head-height, permitting only one axillary branch to develop at each capping, and finally restricting the height at about 2 m. The aim of multiple-stem pruning is 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. The first topping is sometimes done in the nursery. Each lateral bears two crops and is then removed, thus the crop is borne higher and higher up the stems in successive years until a new cycle is commenced. This method is easier and cheaper and is extensively practised; but single-stem pruning keeps the plant shorter, thus facilitating easier harvesting and spraying. It is the system followed at lower altitudes. Agobiado is a variation of multiple-stem pruning, in which the main stem is bent over and pegged to the ground so that orthotropic upright shoots emerge, 3 or 4 of which are allowed to grow. Candelabro is the system of pruning used in Costa Rica, by which 8 main stems are obtained on each tree by 3 prunings.

The best time to prune is the dormant period after harvesting but before the new flush of growth. A light pruning is desirable every year if the crop is healthy and vigorous.

MANURING Coffee responds well to manuring; fertilizer practices vary considerably in different countries. The amount of nutrients also depends upon the expected yield, shading, etc. Nitrogen is by far the most important element. For a small crop of about 900 kg/ha, the nitrogen requirement is about

90 kg/ha, whereas a heavy crop of 1300 kg/ha needs about 120 kg N/ha/year. For best results, a split application of N is recommended. The requirement of phosphorus is high when the plants are young, whereas potassium is necessary in adequate quantities during the development of berries. An excess of K causes Mg deficiency. Proper nutrition is important for the proper quality of coffee also. Foliar analysis is now used as a diagnostic tool. Deficiencies of other elements such as boron, sulphur and zinc have also been reported.

HARVESTING First bearing occurs 3-4 years after planting, and full bearing at 6-8 years. Bearing continues for several years depending upon the environmental conditions and management. The average longevity is 30-40 years in Brazil; 50-70 years is common in other places.

Harvesting, usually called plucking, is done by hand. Fruits mature 7-9 months after flowering. Only uniformly ripe berries can produce good quality coffee; so selective pickings at 10-14 days' intervals, spread over several weeks, are necessary. The berries should be handed over to the factory for processing the same day; the yield of clean dry coffee from ripe berries is 15-20%.

PROCESSING There are two methods of processing: the dry and the wet methods. In the dry method, the berries are spread out thinly and dried in the sun, the process taking about 15-25 days; after drying, the berries are hulled (this method is widely used in Brazil). In the wet method, which is widely used to process arabica coffee in East Africa, the berries are pulped as soon as possible after picking, by feeding into a pulping machine along with water; the parchment coffee is then left for two to four days in fermenting tanks where the sticky mucilage is broken down by micro-organisms; the beans are then washed to get rid of the adhering mucilage, graded, and dried in hot air or in the sun for 8-10 days. The dried parchment is hulled, polished, and graded; the process is known collectively as curing, which imparts a shine to the surface. The produce is then called "clean coffee". The quality of coffee is judged by the characteristics of the raw bean, roasted bean and the liquor.

YIELD

Yields vary considerably; the average yield of clean coffee is about 800 kg/ha in Kenya and South American countries except Brazil, where it is much lower. Good management and care results in yields as high as 1500 kg/ha. Yields are usually higher for robusta.

PESTS AND DISEASES

Coffee is attacked by several insect pests such as the leaf miner, capsid bugs, berry borer, mealy bugs and stem borer. Insecticides that have no persistent residual effect are used to control the pests. BHC is never used because it causes a 'bricky flavour' in the liquor.

Diseases cause more serious losses to the crop than do pests. Coffee berry disease (CBD), caused by the fungus *Colletotrichum coffeanum*, is serious in East Africa. Leaf rust, *Hemileia vastatrix*, is the most serious disease at low altitudes and when the tree is debilitated by over-bearing. Leaf rust can be controlled by spraying Bordeaux Mixture or 50% copper formulations just before the rains start, whereas CBD can be controlled by fungicidal sprays during wet weather. Brown-eye spot, caused by *Cercospora coffeicola* and *Fusarium* bark disease, are diseases of lesser seriousness. Numerous mineral deficiencies and disorders have also been reported in coffee.

AGROFORESTRY POTENTIAL

Coffee is a good species for agroforestry because of its amenability to mixed planting with trees.

RESEARCH INSTITUTIONS AND REFERENCES

Being an important commercial crop, considerable research has been done on all aspects of coffee production. There are coffee research institutes in all major coffee-producing countries. There are also specific journals for coffee: e.g.

Kenya Coffee; Indian Coffee; Coffee and Cacao Journal; Café, Cacao, Thé, etc. Coffee Boards and research stations of several countries also publish bulletins, reports and other literature.

Fig. 27a. Coffee and banana, Arusha, Tanzania.

Fig. 27b. Coffee in partially cleared secondary forest, Brazil.

FIBRES

KAPOK

SCIENTIFIC NAME

Ceiba pentandra (L.) Gaertn.
Family *Bombaceae*
2n = 72 - 84

COMMON NAMES

Kapok, ceiba cotton	
Silk-cotton	(E)
Kapokier	(F)
Kapok, ceiba	(Sp)

USES AND ECONOMIC IMPORTANCE

Kapok, which is obtained from two members of *Bombaceae* family, is a good commercial fibre. The fibre is the floss derived from the inner capsule wall of the fruit. Each hair (fibre) is 0.8-3 cm long, thin-walled, single-celled, with a wide, air-filled lumen. The hairs are lustrous, elastic, water-repellent, long lasting, and resistant to insects and pests. Kapok is 8 times lighter than cotton for the same volume, and 5 times more bouyant than cork. Because of this, kapok is used in mattresses, upholstery, protective clothing, life jackets, aviation clothing, etc.

Very tender pods are eaten in Java. In West Africa, roasted seeds are crushed and used in soups. Seeds contain 20-25% oil used for culinary purposes and soap manufacture. The pressed cake is used as cattle-feed.

ORIGIN AND DISTRIBUTION

It is believed that the cultivated kapok, *Ceiba pentandra* var. *pentandra*, is a natural hybrid between the other two varieties, *C. pentandra* var. *guineensis* and var. *caribaea;* the former originated in the savannas of West Africa and the latter in tropical America.

The main producing countries now are Thailand, Combodia, Indonesia, East African countries, India and Pakistan. Kapok is also grown in Brazil and West Africa.

PLANT CHARACTERISTICS

A deciduous, fast-growing tree, 10-25 m height (var. *caribaea* reaches 70 m height), trunk tapering to the top, with or without sharp spines on trunk and branches; shallow root system; thin crown; dimorphic branches in whorls, usually of three, giving pagoda-form; leaves alternate, crowded towards the end of twigs; flowers and fruits produced after leaf fall, especially in areas with a dry season. Flowers in axillary, many-flowered fascicles; flowers open immediately after sunset, and the petals fall off the following day. Either self-pollinated or cross-pollinated by bees or bats. The size of pod and amount of kapok are proportional to the number of seeds set; at temperatures below 20°C, the growth of the pollen tube is too slow for them to reach the ovary and therefore fertilization does not take place.

The trees come to bearing in the 3rd or 4th year, attain full bearing in 7-10 years, and remain productive up to 60 or more years.

Little work has been done to improve the crop, except for some selection work done in Madagascar, for higher yield.

ECOLOGY

Kapok prefers a warm tropical climate at low elevations (up to 500 m), and a minimum temperature of at least 20°C during the flowering period. It requires 1250-1500 mm of annual rainfall with a rainy period during the vegetative phase and a dry warm period during the flowering and fruiting period. The tree grows best in deep permeable soils free from waterlogging. It is easily damaged by wind.

PHYSIOLOGY AND COMPOSITION

Little is known about the physiology of the plant.

The kapok pods contain by weight, approximately, 44% husk, 32% seeds, 17% floss and 7% placenta. The fibre contains 64% cellulose and 13% lignin; the seeds contain 20-25% oil; and the pressed cake, which is used as cattle feed, contains 26% protein.

AGRONOMY

Kapok trees are planted on field bunds and the border of roads and pavements, or on a plantation scale. Usually propagated by seeds, but vegetative propagation is also possible by cutting of 2-3-year-old branches, 1-1.5 m long and 5-7 cm in diameter. Seedlings are raised from seeds of mature, full-sized pods from high-yielding trees, and are sown in nursery beds at 20 x 30 cm spacing. Germination is rapid; seedlings are transplanted when they are about one year old. Very little is done by way of aftercare. Fully ripe pods are harvested, often by climbing the tree; in dehiscent types, harvesting is done before the pods open. Pods are hulled and the kapok is dried in the sun in cage-like structures; seeds are removed by beating with sticks or mechanically.

YIELD

Trees bear in 3-4 years, when they produce about 100 pods/tree. In full bearing, in about 7 years, the yield is about 350-400 pods per year. One hundred pods yield about 0.5 kg floss.

PESTS AND DISEASES

Kapok is the alternate host of cacao swollen shoot virus in Ghana.

AGROFORESTRY POTENTIAL

Kapok is a good species for agroforestry, especially on field bunds, pavement sides, and wasted lands. It requires practically no extra attention and at the same time offers good economic returns. Its thin canopy, pagoda type branching and deciduous nature are of advantage in agroforestry; however, its shallow root system is a disadvantage in this respect.

RESEARCH INSTITUTIONS AND REFERENCE

Practically no research has been done on the crop.

Kirby, R.H. 1963. Vegetable fibres. Leonard Hill, London.

Fig. 28. Sisal (Photo credit: Centre d'Etude de l'Azote, Zurich).

Fig. 29. Kapok (Photo credit: Centre d'Etude de l'Azote, Zurich.

SISAL

SCIENTIFIC NAME	*Agave sisalana* Perrine
	Family *Agavaceae*
	2n = *c* 138
COMMON NAMES	Sisal (E)
	Sisal (F)
	Sisal (Sp)

USES AND ECONOMIC IMPORTANCE

Sisal leaves provide about 65 per cent of the world's hard fibres for the manufacture of twines, cordages, coarse open-mesh sacks, mattings, etc. About 70% of the world production is used for binder and baler twines for agriculture. One kg of sisal fibre produces approximately 440 m of binder twine or 150 m of baler twine. Sisal was Tanzania's most valuable export commodity till the early 60s, and has again gained prominence in the 70s. The fibre is also used for carpet backing, bags, padding in motor cars and upholstery, reinforcing plaster boards, etc. Sisal poles are used for building in Africa and their pith for filling mattresses.

ORIGIN AND DISTRIBUTION

Agave sisalana is found wild in Central America and Mexico. It was introduced into Tanzania, now the world's largest producer, in 1893. Now it has been widely introduced throughout the tropics, and is produced substantially in Kenya and Brazil also.

PLANT CHARACTERISTICS

Sisal is a xerophytic, relatively short-lived perennial with a short, thick stem and a close rosette of flowers. A long stout flowering shoot known as the pole is produced 7-12 years after planting and thereafter the plant does not produce leaves, and dies. On a dry weight basis, the leaves account for 70%, the bole 8% and the roots 22% in a mature plant.

Roots are fibrous, adventitious, and spreading within a depth of about 40 cm of the top soil. The bearer or anchoring roots, 2-4 mm in diameter, arise from the leaf scar at the base of the bole and extend horizontally up to 3 m. Feeder roots, 1-2 mm in diameter, arise from bearer roots and produce numerous root hairs. The bearer roots get considerably lignified, so that they decompose only very slowly after completion of the life cycle.

The stem or bole is a short, thick structure, about 20 cm in diameter 2 years after planting and reaching a height of about 1.2 m before poling commences. It appears thicker because of the presence of the basal end of the cut leaves. The stem has an apical meristem and a close rosette of about 100 leaves in unharvested plants.

The suckers grow from the axils of the leaves on the rhizomes at the base of the bole, and may be about 2.5 cm in diameter; they grow to about 2 m in length at a depth of 5-15 cm and emerge out of the soil surface producing a miniature sisal plant. Sucker production begins about a year after planting and is most prolific during the first half of the life cycle; as many as 20 suckers are produced from one plant. Rhizomes are white and fleshy with numerous small (2-3 cm long) scale leaves, each with an axillary bud which remains dormant until the sucker is removed. Rhizomes do not have roots, but suckers have adventitious roots at their base. Suckers may be used for propagation.

During the 8-12 year growth period, a sisal plant will produce 200-250 leaves, which unfurl from the central tightly-packed, vertical cabbage at the rate of 2-3 per month, the angle with the stem gradually widening until the lower leaves are almost horizontal. Mature leaves are rigid, linear-lanceolate, usually about 1.2 cm, but sometimes up to 2 m, widest (10-15 cm) in the middle, and dark bluish green in colour.

Each leaf contains about 1100 creamy white fibres which are either the mechanical fibres that constitute 75% of the total fibres and are commercially important, or the ribbon fibres associated with the conducting tissues. Structurally, no further change takes place in the number, length and strength of the fibres after the leaf unfurls.

Flowers are produced on the flowering branches at the tip of the pole after the pole itself attains its full length of about 6 m. There will be 25-40 flowering branches per plant, each about 30 x 2 cm and having about 40 flowers. Flowers shrivel and fall by an abscission layer at the top of the pedicel, so seed setting is rare.

Bulbils are the miniature sisal plants that are borne on the inflorescence; one pole produces as many as 3000. They fall to the ground naturally, are of the same genotype as the parent plant, and have rudimentary roots making them good planting material.

Most of the commercial sisal is *A. sisalana*. Because of the low rate of seed setting it is difficult to breed new varieties. However, an interspecific hybridization programme was started at Amani in Tanzania in 1939 and a few hybrids have been produced, the most promising being hybrid 11648. This is a cross between *A. amaniensis* and *A. angustifolia*, back-crossed to *A. amaniensis*, which produces 500-600 leaves per plant and over 50 t of fibre per ha, compared to about 250 leaves per plant and 20 t fibre/ha for *A. sisalana*. Unfortunately, this hybrid poles about 2-3 years after planting at elevations higher than 600 m.

ECOLOGY

CLIMATE Sisal is a hardy, drought-resistant plant; optimum rainfall is 1200-1500 mm, well distributed throughout the year; it is also grown in areas of 600 mm rainfall per year but yields are lower in those areas. Excessive rainfall is harmful. The number of leaves produced during the life of the plant is fairly constant, so in areas of two rainy seasons per year, the plant completes its life cycle early. Good sunlight and moderate humidity are preferred. Grown from sea level to about 2000 m. Most of Tanzania's estates are below 900 m whereas those of Kenya are mostly above this level.

SOIL Can be grown on a wide range of soils provided they are well-drained and rich in bases, especially calcium.

PHYSIOLOGY AND COMPOSITION

It is a hardy plant requiring good sunlight; it does not tolerate waterlogging.

Sisal fibre contains, on a dry weight basis, 78% cellulose and 8% lignin. Normal commercial fibre contains 10-12% moisture. The leaf cuticle contains about 20% wax.

AGRONOMY

CROPPING SYSTEM Commercial production in estates; also grown as hedge plants by smallholders, especially in the lower altitude areas. Difficulties in extraction of fibres, poor marketing facilities, etc. affect smallholder production.

PROPAGATION Propagated vegetatively by suckers or bulbils. Plants from suckers are not uniform and suckers are few in number per plant. Bulbils produce a more uniform crop, and about 2000 are produced per plant. Bulbils can be collected from the field after they have fallen, or by shaking the poles; they are not collected from plants having leaves with spiny margins.

NURSERY Nursery planting is essential; direct planting in the field results in less uniformity and high maintenance costs. Transplanting from a nursery also helps to reduce the time taken from planting to first harvest. Nurseries are prepared by deep ploughing to give a friable tilth and free-draining soil. Incorporating about 50-100 t/ha sisal waste, either by digging it into the soil or using it as a mulch, has been found beneficial to seedling growth. Bulbils shorter than 10 cm are not used for planting. Selected bulbils are planted shallowly (about 1.3 cm deep) at 25 x 50 cm spacing. If not manured with sisal waste, about 30 kg N/ha is beneficial. Overhead irrigation is sometimes provided. Weeding is done by hand or with herbicides.

Sometimes a primary (or smother) nursery is also raised, where bulbils are planted at 5 x 7 cm spacing and transferred to a second nursery after about 3 months. A primary nursery is useful to eliminate undesirable plants at an early stage and to economize on irrigation and manure.

Plants are transferred to the main field when they are about 50-70 cm long, which occurs in 14-18 months.

At this stage, the plants will have about 15 unfurled leaves and will weigh about 2-4 kg. The fibrous roots are chopped off and the lowest sand leaves are pulled off from the transplants before they are planted.

LAND PREPARATION Land clearing is usually done mechanically. When clearing an old sisal field, the poles are first removed and then the boles are dug out with bulldozers. The debris is broken up and either incorporated to the soil or burned. Fire breaks and feeder lines for leaf transport should be provided.

TRANSPLANTING The transplants are graded according to size; the best are about 40 cm high. Can be planted any time of the year, but the period just before the rains is preferred so that the crop establishes well. Planted 5-7.5 cm deep.

SPACING, PLANT POPULATION The optimum number of plants per hectare and adequate space for cultivation, weeding etc. are the factors to be considered. Sisal is usually planted in double rows, the distance between two rows of each pair being about 1 m; two pairs of rows are spaced 3.5 to 4.0 m apart, and plants in a row are spaced 0.75 to 1.0 m, thus giving a plant population of 5000-6000 plants/ha. Wider spacing between pairs of rows is advantageous for easy management, such as weed and pest control, cultural and harvesting operations etc.

MANURING Good response is obtained to manuring, especially when sisal is grown continuously on the same soil. On soils poor in N, 50-100 kg N/ha is applied per year at frequent intervals; lime deficiency is corrected by liming at the rate of 2-4 t/ha of ground limestone broadcast before the first ploughing. Mulching or manuring with sisal waste is very beneficial.

AFTERCARE During the early years of growth, weed control is very important. Prominent weeds are perennials, such as couch grass *(Digitaria scalarum)*, nut grass *(Cyperus* spp.) and lalang

(Imperata cylindrica). Weeds may be controlled by hand weeding, slashing, tractor cultivation, or herbicides. Leguminous cover crops, such as *Calopogonium mucunoides*, *Pueraria phaseoloides* and *Centrosema pubescens*, are grown in the interspaces between double rows, and they suppress weeds, control erosion, and improve the soil fertility. Intercropping is also practised during the first 2-3 years after planting sisal in the field. Maize, beans, cotton and pineapple are common intercrops.

Sisal suckers may be removed as they are produced and the small sand leaves at the base of the plants may be removed to facilitate weeding.

HARVESTING Leaves are harvested by hand using small knives with straight edges. The first cutting is done when the average height of the plants is 1.5 m and the plant has produced about 120 leaves, which happens 2-3 years after planting. The harvesting is usually carried out once a year; in hot humid conditions, as in Indonesia, it is done once every six months. Too frequent cutting is wasteful of labour and excessively long cutting intervals lead to losses through withering of older leaves. Over-cutting reduces plant vigour; about 25 leaves should be left after the first cutting, which can be reduced to 18-20 at subsequent cuttings. One labourer can cut about one ton of leaves per day. There will be 5-8 cutting cycles per plant.

PROCESSING Decortication is the process by which the fleshy tissue, which forms about 96% of the weight of leaves, is removed from the fibres. Leaves should be decorticated within 24 hours of cutting. Water is sprayed continuously on the decorticator drums that wash the fibres and carry away the waste leaf pulp. A modern decorticator requires 36-45,000 l of water per hour. Fibres from the decorticator are graded for length and dried as quickly as possible by spreading them thinly on three wires stretched over poles in the sun. This brings the moisture content down from 60% to the permissible limit of 10% in 4-8 hours in good weather; over-exposure results in sun-burning. The fibres become stiff on drying, and are then 'brushed' by beating lightly to separate individual fibres from each other and to remove the short fibres, called tow. Long fibres constitute about 95%, and tow about 5-6% of the total output. The long fibres are graded according to length, freedom from tow, colour (creamy white is the preferred colour), etc. There are 5-6 grades of long fibres and 2 of tow.

YIELD

Yields are usually expressed in tons of fibre per cycle. Average yields are 11-12 t/ha; intensive management produces about 20 t/ha. With an average cutting cycle of 6 cuttings per plant at annual intervals, a 12 t/ha crop yields 2 t fibre/ha in one year. Recovery of dried fibre is 4% of fresh leaves on weight basis. An annual output of 1500 tons of fibre is regarded as the optimum for one decorticator, for which 750 ha of sisal cut once a year are required. Including the area for roads, nursery, fallow for re-planting etc., the total area of the plantation to produce 1500 t fibre per annum is approximately 1200 ha.

PESTS AND DISEASES

Sisal weevil, *Schyphophorus interstitialis*, (whose larvae kill young plants by boring into their boles) is a major pest. Zebra disease, caused by the fungus *Phytophthora* spp., is usually found in areas with poor drainage. The fungus *Aspergillus niger* causes bole rot, resulting in yellowing of leaves and the death of plants.

AGROFORESTRY POTENTIAL

Sisal is an important crop for agroforestry because of its hardy and drought-resistant nature and the possibilities of intercropping. But it is not an economical crop for small-scale production.

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SPICES

CARDAMOM

SCIENTIFIC NAME	*Elettaria cardamomum* Maton Family *Zingiberaceae* 2n = 48
COMMON NAMES	Cardamom (E) Cardamome (F) Cardamomo (Sp)

USES AND ECONOMIC IMPORTANCE

Cardamom, known as the "queen of spices", is an important spice used for flavouring, chewing and medicinal purposes. The seeds contain 2-8% of a strongly aromatic volatile oil having a pleasant smell, which is used in perfumery, for flavouring liqueurs etc. and as a stimulant. The seeds are also included in betel quid with arecanut and leaves of betel vine.

ORIGIN AND DISTRIBUTION

Cardamom is indigenous to the moist evergreen forests of the hilly regions on the Western Ghats of southern India. India is the largest producer (with cultivation confined to the southern states of Kerala, Karnataka and Tamil Nadu) and exporter. Guatemala and Sri Lanka are the other major producing countries. Principal importing countries are in Western Europe and the Arab region.

PLANT CHARACTERISTICS

A herbaceous perennial, 2-5 m tall; has a branched subterranean rhizome, from which arise 10-20 erect leafy shoots and panicles. Roots are superficial; shoots form a thick clump; leaves have long sheaths, lamina lanceolate and acuminate dark green, and are long and narrow (30-90 x 5-15 cm). Inflorescence arises from root-stock at the base of leafy shoot, 60-120 cm long; and is an erect or decumbent, slender panicle. Flowers are hermaphrodite, about 4 cm long, self-sterile; pollination is by insects. Fruit is a trilocular capsule, fusiform to globose, pale green when mature, with 15-20 seeds per fruit. Seeds about

3 mm long, dark brown, aromatic.

A few agronomic varieties (races) have been recognized; the most important are Malabar and Mysore. The former possesses medium-sized plants, prostrate panicles and small, globose, rounded or ovoid pods. The Mysore variety has robust plants, coarse leaves, erect panicles and large, three-cornered, ribbed pods. It is suited for cultivation at higher elevations.

ECOLOGY

Cardamom thrives best in evergreen tropical forests at 800-1500 m elevation where there is a well-distributed annual rainfall of 1500-5000 mm and a temperature range of 10-33°C, moderate shade, and protection from strong winds.

The crop is raised chiefly on well-drained, rich, forest loams and deep, good-textured soils well-supplied with humus.

PHYSIOLOGY AND COMPOSITION

The crop prefers partial shade and fertile soils; it cannot withstand waterlogging.

The aroma and therapeutic value of cardamom is due to the volatile oil contained in the seed (2-8%). The capsules contain: protein 10%; fat 2%; carbohydrate 42%; fibre 20%; ash 6%; and water 20% or less, depending upon the degree of drying.

AGRONOMY

CROPPING SYSTEM Cardamom is grown under coffee or areca palms, or in cleared forest areas with thinned overhead shade.

PROPAGATION Cardamom is propagated by planting a section of the rhizome called the 'bulb', from an established clump, or by transplanting the seedlings from a nursery raised from seeds.

Clonal propagation permits planting of high-yielding clones and such plants start yielding earlier. But the practice is no longer popular because of the prevalence of 'Katte' virus.

For raising nursery seedlings, seeds are collected from plump, fully ripe capsules from disease-free clumps. The seeds are cleared of mucilage, soaked overnight in water and sown broadcast in raised beds of loose fertile top-soil rich in humus, 60 cm wide, 20-30 cm high and 3-4 m long. After sowing, the seeds are covered with a thin layer of soil and mulch, and the nursery is adequately watered and provided with thatched shade. Germination starts in 30-40 days and continues much longer. Seedlings, when 3-4 months old, are transferred to a second nursery and they remain there for at least one year, during which they are sprayed with Bordeaux mixture occasionally to keep them free of disease. One kg of seeds produce enough seedlings for one hectare.

PLANTING One or two seedlings are planted in pits 60 x 60 cm and 45 cm deep, 2-3 m apart; seedlings are planted 5-7 cm deep; the soil around is well pressed and the seedlings are tied securely to a stout wooden stake to prevent them being laid low by heavy rains and winds.

AFTERCARE Weeding at regular intervals, especially during the early years, clearing and digging the soil around the clumps, gap filling, mulching, removal of old and drying stems, regulating the shade, etc. are the regular aftercare operations.

MANURING Concentrated organic manures such as castor cake, bone meal, fish manure etc. and fertilizers are given commonly to provide 33-66 kg N, 33 kg P_2O_5 and 60-100 kg K_2O/ha. If planted with arecanuts, cardamom benefits by the cultural practices and manuring given to arecanut.

HARVESTING Cardamom starts bearing three years after planting and reaches full bearing in 7-8 years. The economic life is 10-15 years.

In India, flowering commences in April and continues until July. Fruits mature 3-4 months after flowering; several pickings are necessary. The capsules with peduncles are harvested just before full ripening so as to avoid splitting of the capsules during drying.

PROCESSING Harvested capsules are dried in the sun or with artificial heat, for 3-4 days. Artificial drying retains the light green colour preferred for export. Sometimes, they are bleached with sulphur fumes.

YIELD

Average annual yield of dried capsules is 150-300 kg/ha from a well-maintained plantation. The number of dried capsules amounts to 20-25% of the number of fresh fruits.

PESTS AND DISEASES

The major malady of cardamom is the mosaic virus known as 'Katte' or 'marble' disease, which is transmitted by the aphid *Pentalonia nigronervosa*, and is characterized by mottling, curling and reduction in size of the new leaves. Planting disease-free clumps and killing the vector insects are the recommended control measure. Thrips *Taeniothrips cardomomi* are the most serious insect pests.

AGROFORESTRY POTENTIAL

Cardamom is a good species for agroforestry; in fact, as practised now, the cultivation of cardamom constitutes a good agroforestry system.

RESEARCH INSTITUTIONS

Very little research has been done on cardamom. The institutions that carry out research on cardamom in India are:
Central Plantation Crops Research Institute (CPCRI) of ICAR, Research Centre for Cardamom at Appangala, Karnataka State; and the Agricultural Universities of Kerala and Karnataka States, India.

CINNAMON

SCIENTIFIC NAME	*Cinnamomum zeylanicum* Breyn Family *Lauraceae* 2n = 24
COMMON NAMES	Cinnamon (E) Cannelier de Ceylan (F) Canelo de ceilán, Canelero (Sp)

USES AND ECONOMIC IMPORTANCE

Cinnamon bark (quills) is used as a condiment for flavouring cakes, confections and in curry powder and perfumes. Cinnamon oil distilled from both the bark and dried green leaves is also used in perfumes and in the synthesis of vanillin.

ORIGIN AND DISTRIBUTION

Believed to have originated in Sri Lanka or on the Western Ghats in south-western India. Cinnamon is reported to have reached Europe in commerce in very early times. Now it is cultivated in Sri Lanka, southern India, the Seychelles, Madagascar and Brazil; the best quality cinnamon is produced in Sri Lanka.

PLANT CHARACTERISTICS

An evergreen tree, up to 15 m high if left undisturbed. But when cultivated, repeated harvesting of the stems for the bark imparts a bushy appearance. Leaves are stiff, evergreen and aromatic, reddish when young, lamina ovate or elliptic, 5-17 to 3-8 cm, strongly veined. Stems are branching; bark is aromatic; flowers are borne in axillary and terminal panicles at the end of twigs. In Sri Lanka and South India, trees flower December-January, fruits ripen in about 6 months. Different types of cinnamon have been recognized and some are known to be more aromatic and superior. However, little or no work has been done on the improvement of the crop.

ECOLOGY

Cinnamon grows up to about 1800 m altitude; the best cultivated cinnamon however, is grown at lower altitudes. Humid tropical evergreen rainforest conditions favour the best growth of cinnamon.

PHYSIOLOGY AND COMPOSITION

During the early stages of establishment the young plants are lightly shaded; fully-grown cinnamon is also to some extent adaptable to shade.

The principal aromatic substances in cinnamon are eugenol and cinnamic aldehydes; the bark oil contains about 10% eugenol and 60% cinnamic aldehyde, whereas the leaf oil contains 65-95% eugenol and less than 3% aldehyde.

AGRONOMY

CROPPING SYSTEM Not usually grown as a smallholder crop because of the difficulty of extracting oil from small lots of leaves; but grown in small scale for bark only. It withstands shade to some extent and is, therefore, grown with other species. Promising results have been obtained in trials with cinnamon as an understorey crop in coconut plantations.

PROPAGATION Usually propagated by seed and seedlings are raised in a nursery. Seeds are protected from birds by netting the trees or putting bags around ripening seeds; harvested seeds are heaped to allow rotting of pulp, then washed and dried in the shade, and sown thickly in finely-prepared nursery beds under light shade. The seedlings are transferred to baskets when they are 4-5 months old to facilitate transportation to the field, and are ready for planting after a further period of 4-6 months, when they will be about 45-60 cm tall.

LAND PREPARATION, PLANTING Planting holes are dug 2-3 m apart in freshly cleared areas; tall trees are left at about 15 m intervals to provide light shade. An organic mulch is provided after planting, but waterlogging in the planting holes is to be avoided.

AFTERCARE, PRUNING Weeding is done during early years until the plant canopy develops and suppresses weeds. The main stem is stumped a few centimetres above ground after 2 years of growth in the main field, and the cut end is covered with earth and cow dung. This facilitates formation of fresh shoots, 4-6 of which are allowed to grow and are kept straight by timely pruning of the twigs and branches for a further 2 years before they are harvested.

HARVESTING, PROCESSING AND GRADING The stems are cut when they are about 2 m high and 2-5 cm in diameter, which is after about 2 years' growth. Harvesting is done in rainy periods which facilitates easy peeling of the bark and also regeneration of the plant. After trimming off the leaves and twigs from the stem, a longitudinal slit is made along the stem, and the bark is peeled off either full or half the circumference. The bark is then fermented in heaps for a day and the outer skin and green cortex are scraped off (sometimes peeling is done after scraping). The scraped bark is dried when it contracts to a quill or pipe form. The dried quills are kept one inside the other and the compound quill,about 1 m long, is again dried and rolled daily by hand to make it compact. Best quality quills are obtained from the thin bark from the middle portion of shoots in the centre of the clump.

The quills are graded into 4 categories based on the thickness of bark, appearance, colour and aroma. The best quality bark is thinner than 0.5 cm and is pale brown. Broken quills are called quillings. Bark from twisted branches and the inner side of twigs is called feathering; trimmings from cut shoots, shavings of outer and inner bark, etc. are exported as chips.

Cinnamon oil is extracted by distillation from both the bark and the leaves. Under smallholder conditions, it may not be economical to have distillation sets as there may not be enough material for running the unit and small-scale distillation sets have not yet been developed. The method and time of distillation and the containers used for the purpose affect the quality of oil.

YIELD

Yield of quills from the first cutting after 4-5 years is 50-60 kg/ha per year, increasing to 150-250 kg in subsequent years; yield declines after about 15 years.

PESTS AND DISEASES

The crop is fairly free of diseases and pests. Stripe canker, a fungus disease, caused by *Phytophthora cinnamomi*, causes some damage in young trees.

AGROFORESTRY POTENTIAL

The crop has good potential for agroforestry because of its adaptability to shady conditions, amenability to combination culture, and suitability for marginal areas and low-input systems.

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SPICES

CLOVE

SCIENTIFIC NAME	*Syzygium aromaticum* Merr. et Perry syn. *Eugenia caryophyllus* (Sprengel) Bull. et Harrison *E. aromatica* Kuntze Family *Myrtaceae*
COMMON NAMES	Clove (E) Clove de girofle (F) Clavo de olor (Sp)

USES AND ECONOMIC IMPORTANCE

Cloves, one of the oldest Oriental spices, are the dried unopened flower buds of *S. aromaticum*. Cloves are an essential ingredient in the preparation of curry powder and mixed spices, and are used in medicines as a stimulant, carminative and antispasmodic. Clove oil, produced by distillation of cloves, is used in the manufacture of perfumes, in medicines, in the production of vanillin, etc.

ORIGIN AND DISTRIBUTION

Cloves are believed to be native to the small volcanic islands in the Moluccas, which continued to be the sole producers until the end of the 18th century. Now they are also produced in other parts of Indonesia, India, Zanzibar, Madagascar, the Seychelles, and elsewhere. Zanzibar and Madagascar are the principal exporters.

PLANT CHARACTERISTICS

The tree is a small evergreen that grows to about 15 m; it has a conical shape when young, later becoming cylindrical.

The root system is shallow with fibrous lateral roots up to about 10 m, originating from a short tap root, which produces 2-3 primary sinkers reaching up to 3 m depth. The trunk forks near the base to 2-3 erect branches.

Leaves opposite, aromatic; petiole short but swollen at the base, lamina 7-13 x 6 cm; leaves pink when young and turning dark green with maturity.

Inflorescence terminal, about 5 cm-long paniculate cymes, 3-20 flowers per inflorescence. Flower buds 1.3-2.0 cm long. Flowers hermaphrodite with reddish colour. Fruits, called mother of cloves, are fleshy drupes, dark red, oblong-obovoid, contains one or sometimes two seeds. Dried flower buds (cloves) about 1.5 cm long, dark in colour; domed rounded head with prominent sepals. Most of the flowers drop off without fruit setting; flowers are cross-pollinated, mainly by bees.

No recognizable varieties or cultivars have been identified and very little work has been done on the improvement of the crop.

ECOLOGY

In its original habitat in the Moluccas, the annual rainfall is 200-350 cm and temperatures 25-33°C. In Zanzibar and Pemba, the temperatures are 25-30°C and rainfall 150-200 cm per annum. Cloves appear to thrive best in maritime climates at low altitudes in the tropics, but drier weather is desirable for harvesting and drying.

The best clove-growing soils are deep, sandy, acid loams.

PHYSIOLOGY AND COMPOSITION

Not much is known about the plant's physiology. It does not tolerate waterlogging; similarly, a continuously humid climate is not preferred. The plant prefers shade in the early stages.

Commercial cloves contain approximately 16-19% clove oil, 13% tannin, 16% water, and 10% fibrous matter. The inflorescence stalks also contain 5-6% clove oil. Clove oil contains 80-90% eugenol (75-85% in oil from the leaves).

AGRONOMY

Usually planted by cutting lanes through the forest in new areas, or under-planted when re-planting old plantations, or interplanted with banana, cassava, cacao, etc. to get the required shade and protection from wind in the early stages of growth.

Propagation is by seed for which fully ripened, fresh seeds are used; they are hulled and washed and sown shallow at 20 x 20 cm spacing, with radicles downwards, in shaded nurseries. Watering and shading are reduced when seedlings get older; transplanted when about 12-15 months old with a ball of earth adhering to the roots. Occasional success has been reported in vegetative propagation (layering, approach-grafting, etc.).

Usual spacing in the field is 9 x 9 m; sometimes they are planted closer and later thinned. Ring weeding around the seedlings is carried out, especially to protect them from *Imperata cylindrica* Beauv. grass. The plants are not usually pruned. Good response has been reported to organic manuring and nitrogen.

Trees begin flowering in about 6 years; are full-bearing in 15-20 years; production continues until 70-80 years. There is considerable variation within the years; a good crop is expected once in about 4 years. Buds are ready for harvest 6 months after initiation. Harvesting is by hand; inflorescence clusters are picked up before the buds open. Upper branches are lashed together and distant branches are pulled nearer by a crook for facilitating harvesting. While harvesting, care should be taken that only as few branches as possible are broken.

Harvested flower buds are dried immediately in the sun in thin layers on mats on cement floors; quick drying gives best quality cloves. In good weather, drying will be completed in 4-7 days.

The clove stems, which are approximately one-fifth the weight of green cloves that have been separated from them, are also dried and used for extraction of oil, the oil content being 6% of dried weight.

In Zanzibar, there are two flowering seasons: the *mwaka* crop from July-October and the *vuli* crop from November-January.

YIELD

The average annual yield is 3 kg dried cloves/tree; in favourable years, up to 20 kg/tree is obtained. There are records of single trees yielding up to 90 kg dried cloves per year. Best quality cloves should be sound, bold, somewhat regular, containing not more than 5% stems and extraneous matter and less than 16% moisture.

PESTS AND DISEASES

The major disease is called "sudden death", which is believed to be caused by the fungus *Valsa eugeniae*, which causes blocking of the vessels. Die-back caused by the fungus *Cryptosporella eugeniae* is also a serious pathogen. Termites attack the young seedlings both in the nursery and during the first few years in the field.

AGROFORESTRY POTENTIAL

In the humid, low-altitude areas of the tropics, clove can be used advantageously in agroforestry as an overstorey species, and it gives high economic returns.

REFERENCES AND RESEARCH INSTITUTIONS

Not much research has been done on the tree.

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SPICES

GINGER

SCIENTIFIC NAME

Zingiber officinale Rosc.
Family *Zingiberaceae*
2n = 22

COMMON NAMES

Ginger	(E)
Gingembre	(F)
Jengibre	(Sp)

USES AND ECONOMIC IMPORTANCE

Ginger is one of the earliest oriental spices valued for its flavour, pungency and aroma, and is still very popular. The dried rhizomes constitute the ginger of commerce. An essential oil is also extracted from the rhizome, but it lacks pungency. Ginger is used in the production of ginger ale, ginger beer, etc. and in various medicines in India and the Far East.

ORIGIN AND DISTRIBUTION

Native to tropical Asia, possibly India. Major producing countries are China, India, Nigeria, Jamaica, Sierra Leone, Fiji and Australia.

PLANT CHARACTERISTICS

A slender perennial herb, to 1 m tall. Leafy shoots, usually 8-12, are annual, erect, about 50 cm long with dark green laminae that are about 25 cm long. The rhizomes are thick and hard, palmately branched, pale yellow within, covered with small scales, and with fine fibrous roots in top layers of the soil. Flowers are seldom produced; they arise from root-stock, 15-25 cm long.

Ginger can grow as a perennial, but is cultivated as an annual, maturing 9-10 months after planting.

The number of clones is limited. In India, the type introduced from Brazil and known as 'Rio de Janeiro' is reported to be a high-yielder.

ECOLOGY

CLIMATE Ginger is cultivated in the tropics from sea level to about 1500 m altitude with 1500-2500 mm of annual rainfall, or irrigation. It prefers a short dry season with high temperatures towards maturity.

SOILS A deep, well-drained, friable loam, rich in humus is ideal for ginger. Ginger is usually the first crop grown after clearing the forest. It is also grown in hill slopes.

PHYSIOLOGY AND COMPOSITION

Ginger does not withstand waterlogging. It can tolerate partial shade though it is grown on large areas in the open.

Dry ginger contains about 10% moisture and 1-3% of volatile oil. The pungent principle of ginger is the zingerone $C_{11}H_{14}O_3$, which is present in the oleoresin.

AGRONOMY

CROPPING SYSTEM Usually grown once in three years in rotation with cassava, sweet potato, yam, banana, groundnut, vegetables, etc. It is also grown mixed with other crops that give partial shade such as pigeon pea, and as an intercrop in tree crop areas.

PROPAGATION Propagated by pieces of rhizomes, 2.5-5 cm long and having at least one sound bud; sometimes the setts are stored for sprouting before sowing.

LAND PREPARATION A good tilth is required; usually planted in raised beds or in rows between rows of taller crops.

PLANTING Planted in May in India and Jamaica, and in September in Queensland. Seed rate varies depending upon the extent of mixed cropping; the usual rate is 1000-2000 kg/ha. When planted in beds, spacing is 20-30 cm between plants in either direction and planting depth about 7 cm. Leaf mulch is provided after planting.

AFTERCARE The new shoots emerge in 10-20 days, hand weeding is done 2-3 times, and plants are earthed up along with each weeding.

MANURING Ginger is a heavy feeder; it is usually grown with heavy dressings or organic manures, applied at the time of seedbed preparation. Moreover, application of fertilizers, particularly N and K, gives high yields. The fertilizer recommendation in India is 50-60 kg N, 30-40 kg P_2O_5 and 100-120 kg K_2O per hectare. Nitrogen is given in two equal instalments - basal dressing and top dressing at the time of second earthing-up.

HARVESTING The crop matures about 9 months after sowing when the leaves turn yellow and wither off. For manufacture of preserved ginger, the crop is harvested before it is fully mature so that the fibre content and pungency are low. Harvesting is by hand digging. The crop can also be left unharvested for sometime.

PROCESSING AND STORAGE The rhizomes are cleared free of the adhering soil and soaked in water, scraped carefully to remove the outer skin and then dried in the sun for 4-5 days. Sometimes the peeled ginger is soaked in thick lime water for some time, fumigated with sulphur fumes for 12 hours and dried in the sun. The process is repeated once or twice more until a fully bleached white produce is obtained.

YIELD

Yield varies considerably; in India it is about 10 t/ha of fresh ginger and in Australia about 20 t/ha. With good cultural practices, the yield can be much higher.

PESTS AND DISEASE

The fungus *Pythium aphanidermatum* causes serious soft rot of the rhizomes; crop rotation and good drainage are the best means of control. Leaf spots and bacterial wilt are also common diseases. Root knot nematode *Meloidogyne* spp. also attacks the crop. The shoot-borer *Dichocrosis punctiferalis* causes some damage.

AGROFORESTRY POTENTIAL

Because of the shade tolerance of ginger, it is a good species for agroforestry, but it is not very well suited to marginal and infertile soils.

RESEARCH INSTITUTIONS AND REFERENCES

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Regional Station, Calicut, Kerala, India.

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Fig. 30. Cardamon under trees (Photo credit: Centre d'Etude de l'Azote, Zurich).

Fig. 31. Turmeric under coconuts (Photo credit: CPCRI, Kasaragod, Kerala, India).

Fig. 32. Ginger under coconuts (Photo credit: CPCRI, Kasaragod, Kerala, India).

Fig. 33a. Pepper garden (Photo credit: Centre d'Etude de l'Azote, Zurich).

Fig. 33b. Pepper interplanted with rubber, Brazil.

SPICES

PEPPER

SCIENTIFIC NAME *Piper nigrum* L.

Family *Piperaceae*

2n = 52

COMMON NAMES

Pepper, black peper	(E)
Poivre noir	(F)
Pimienta negra	(Sp)

Red, green, and sweet pepper are *Capsicum* spp. of *Solanaceae* family.

USES AND ECONOMIC IMPORTANCE

Black pepper, known as the king of spices, is the most important and one of the oldest of all spices. It is used as a flavouring agent, in powdered form after grinding, and has extensive culinary uses. White pepper is the fruit, whose mesocarp has been removed by retting in water. Pepper oil is distilled from fruits and used in perfumes. Pepper was one of the first articles of trade between the East and the West. Annual world export of pepper is 50,000-80,000 tons.

ORIGIN AND DISTRIBUTION

A native of the Western Ghats of India. Its cultivation has been prevalent in the Malabar coast of India, and many parts of southeast Asia even before the 17th century. In addition to India, Indonesia (Sarawak) is the other major producer. Pepper is also cultivated in other parts of southeast Asia, Brazil and Malagasy Republic.

PLANT CHARACTERISTICS

Pepper is a perennial woody climber growing up to 10 m height. Depending upon the type of standard used, the overall appearance of the plant will vary.

The main roots at the base of the stem are about 10-20, 3-4 m long, and are adventitious. In addition, there is an extensive mat of feeding roots near the soil surface.

The framework of the plant is given by the orthotropic climbing stem, which becomes stout, woody, 4-5 cm in diameter; internodes 5-12 cm long; nodes swollen; each node has an axillary bud and short adventitious roots which adhere firmly to the support (standard). The axillary buds grow out to produce plagiotropic fruiting branches.

Leaves are present on both climbing and fruiting branches; they are alternate, simple; petiole 2-5 cm long; lamina ovate, 8-20 x 4-21 cm, dark green and shiny above with 5-7 prominent veins.

Flowers are borne opposite leaves on fruiting branches in pendant spikes, 3-20 cm long, up to 150 cm per spike. Flowers unisexual (monoecious or dioecious) or hermaphrodite, very small, white to brownish in colour. Fruit is a drupe, 4-6 mm in diameter, with pulpy mesocarp; exocarp turns bright red when ripe; fruiting spike 5-20 cm long. Seeds are 3-6 mm in diameter; 100 seeds weigh 5-10 g.

Flowering begins at the base of the spike and continues towards the tip over a week. Rains help in pollination because pollen occurs in glutinous masses and light rain breaks up the mass and increases the efficiency of pollen distribution. Hermaphrodite cvs are self-fertile, and self-pollination can occur without the action of rain or wind. Pollination is confined to individual spikes.

Pepper is a perennial plant giving economic yield until about 15-20 years after planting, after which the garden is replanted. A large number of cvs occur in India, where *Balancota* (large leaves, long spikes, regular yields) and *Kalluvally* (small leaves, large berries) are the two most popular ones. Two cvs are recognized in Sarawak: *Kuching* (large-leaved, susceptible to foot-rot disease) and *Sarikei* (small-leaved). High-yielding hybrid *Panniyur-1* has been developed at the Pepper Research Station, Panniyur, Kerala, India.

ECOLOGY

CLIMATE Pepper is a plant of hot humid tropical climates at low altitudes with rainfall from 2000-2500 mm per annum which needs to be fairly well-distributed. It cannot withstand waterlogging and prolonged droughts.

SOILS Pepper can be grown on a variety of soils provided they are fertile and well-drained. The ideal soil is a friable alluvium rich in humus with a pH about 6.

PHYSIOLOGY AND COMPOSITION

Waterlogging encourages the growth of fungi causing wilt diseases. The plant needs support (called "standard") in the form of wooden or concrete poles or living trees. Even though yields are higher with dead standards, pepper is widely cultivated with living standards and it can withstand shade.

Pepper contains 5-8% piperine, an alkaloid, $C_{17}H_{19}NO_3$. Its pungency is due to the resin in the mesocarp, chavicine. Thus white pepper is less pungent than black pepper. Pepper also contains 1-2% volatile oil.

AGRONOMY

CROPPING SYSTEM Since pepper needs support, it is traditionally cultivated by planting at the base of existing trees, or by using specially planted quick-growing shade and support trees such as *Erythrena indica* and *E. lithosperma.* Commercial plantations of sole crops of pepper on dead or living standards are common, especially in Brazil. But it is widely grown interplanted with coffee, arecanut, Ceiba cotton, and other tree crops.

PROPAGATION Propagated vegetatively by cuttings. In India, stolons from the base of the vines are used for planting. In Sarawak, Malaysia and Indonesia, the cuttings are taken from the upper part of the orthotropic shoots of vines less than 2 years old. The terminal bud of the selected shoot is broken off and the leaves and small branches between the 3rd and the 7th nodes from the apex are stripped off. After regeneration of the terminal bud in about 2 weeks, the shoot is cut below the 7th node and the cutting, 50-60 cm long, may be planted in the nursery for rooting or planted *in situ* in the main field.

Cuttings are planted 3-4 nodes below the soil surface; sometimes rooting is done in polythene bags filled with potting mixture, which facilitates transport of the rooted cuttings. Rooted cuttings are also produced by layering. The nursery is shaded with coconut leaves and other plant parts.

LAND PREPARATION While planting pepper in fresh areas with live standards, the land is cleared and the 1 m-long cuttings from the standards are planted first at 2.7 x 2.7 m spacing and 60 cm depth. When they are established in about 6 months' time, rooted (sometimes also unrooted) cuttings are planted at the base of the standard on about 10 cm-elevated platforms. Since planting is usually done on hill slopes, soil conservation measures have to be adopted.

PLANTING, PLANT POPULATION Planting is done in the rainy season so that the plants are easily established. Three to four vines are planted at an angle of about 45° at a distance of 75 cm from the base of the standard and trailed on to the standards by dried fronds and palm leaves. In India, the northern aspect of hills is preferred, and planting is done on the northern side of the standard to protect the tender young vines from the scorching southern sun - when sun comes to the northern hemisphere, it will be rainy season in the pepper areas there. Usually spacing is 2.3-2.7 m square with a plant population of 1700-1400/ha.

AFTERCARE Young vines are shaded with dry leaves to protect them from sun, watered as necessary, and occasionally tied to the standard to keep them adhered. Pruning of the growing main climbing stem induces development of lateral fruiting branches. The vines are pruned at periodic intervals for a total of 7-8 times before they reach the top of the 3 m standard posts. Plants trailed on live standards are not allowed to go to greater heights, so as to facilitate harvesting. Lopping the branches of support trees is a regular operation to allow penetration of light, and to get green leaves for mulching and manuring the pepper plants. Vines are not permitted to produce flowering spikes until they are more than 2 years old.

NUTRITION Pepper responds well to fertilizers, and high amounts of nutrients are needed for sustained production. Fertilizers to supply 220 g N, 300 g P_2O_5 and 180 g K_2O per vine per annum are considered optimum. Mulching and addition of organic matter are strongly recommended.

HARVESTING Fruits ripen about 4 months after flowering, and 5-6 months after emergence of flower spikes. First harvest is about 3 years after planting. Spikes are picked by hand after a few of the fruits have turned red and the rest are yellow or green, and during the harvesting season, the spikes are picked once in every 10 days.

The berries are separated from the spikes by rubbing by hand and winnowing, and the berries are dried in the sun for 3-4 days to about 12% moisture content.

PROCESSING For producing white pepper, the spikes are crushed lightly and then soaked in sacks in slowly running water for 7-10 days, by which time the mesocarp is rotten. The spikes are then trampled under feet to loosen the stalks and skins, and then washed in sieves and dried in the sun.

YIELD

Fresh green berries give about 33% black pepper or 25% white pepper. Yields vary depending upon the level of management. Intensively cultivated gardens yield about 2 kg green pepper per vine in the third year, 4-8 kg annually in 8th-15th years, decreasing with age.

PESTS AND DISEASES

Pepper is affected by shoot rot caused by *Phytophthora palmivora* and wilt diseases caused by many fungi, mainly *Fusarium* spp., and aggravated by poor soil conditions such as low fertility and impeded drainage. Sprayings with 1% Bordeaux mixture after heavy rains, and field sanitation are necessary. The root-knot nematode *Meloidogyne javanica*, and the burrowing nematode *Radopholus similis* also attack pepper.

Pepper production in Brazil is threatened by a devastating disease of unknown aetiology. The vines are completely destroyed within about 5 years after planting, necessitating replanting. As a result, pepper cultivation is being abandoned in many parts of Brazil.

AGROFORESTRY POTENTIAL

Pepper is widely cultivated with living supports, and it can withstand shade. Thus pepper cultivation is usually an agroforestry practice.

MAJOR RESEARCH INSTITUTIONS AND REFERENCES

Central Plantation Crops Research Institute (ICAR), Regional Station, Calicut, Kerala, India.

Pepper Research Station, Kerala Agricultural University, Panniyur, India.

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SPICES

TURMERIC

SCIENTIFIC NAME	*Curcuma longa* L.	
	Family *Zingiberaceae*	
	2n = 63	
COMMON NAMES	Turmeric	(E)
	Curcuma, safran des Indes	(F)
	Cúrcuma	(Sp)

USES AND ECONOMIC IMPORTANCE

Turmeric is an important condiment among the people of South and Southeast Asia, and is an indispensable ingredient and colouring agent for curry powder. It also has medicinal values, and is used externally for pain relief and internally as a stimulant. It is also used as a cosmetic by women and in Hindu religious ceremonies.

ORIGIN AND DISTRIBUTION

Believed to be domesticated in South or Southeast Asia. The crop is widely distributed throughout the tropics, but its cultivation as a condiment is confined largely to India and Southeast Asia. India is the largest producer, the crop being cultivated on about 60,000 ha.

PLANT CHARACTERISTICS

Turmeric is a perennial herb to 1 m tall with a short stem and a primary tuber at the base of the aerial stem bearing many rhizomes with a distinctive smell and bright orange-coloured flesh. Leafy shoots to 1 m tall, 6-10 leaves, bladeless sheaths, leaf sheaths forming a pseudostem. The secondary and tertiary branching at the base gives a dense clump-like appearance to the plant. Inflorescence is borne apically on leaf shoots, 10-15 x 5-7 cm in size. Turmeric can grow as a perennial, but is cultivated as an annual; it matures 9-10 months after planting.

A number of cvs are popular in India; they are distinguished by the names of the localities in which they are grown and they show considerable variation in rhizome size and colour. Hard, bright-coloured rhizomes are preferred for dyeing; softer, more aromatic, ligher-coloured ones produce the best spice.

ECOLOGY

CLIMATE Grown in areas with annual rainfall of 1000-2000 mm; in drier areas irrigation is required. Grows from sea level up to 1500 m altitude in the Himalayan foothills. A warm moist climate is preferred.

SOIL Thrives best on loamy or alluvial soils of loose and friable texture. Well-drained and fertile soils, rich in organic matter, give best yields. The plant does not withstand waterlogging.

PHYSIOLOGY AND COMPOSITION

Turmeric grows well in the open as well as in partial shade when intercropped in plantations of fruit trees and other perennial agricultural species. It does not tolerate waterlogging or prolonged drought.

The approximate chemical composition of dried turmeric is: water 13.1%; protein 6.3%; carbohydrate 69.4%; ash 3.5%; fibre 2.6%. The colouring agent in turmeric is curcumin, $C_{12}H_{20}O_6$. On distillation, it yields 1.5-5% of a volatile aromatic, orange-red oil, the main constituent of which is termerone, $C_{15}H_{20}O$.

AGRONOMY

CROPPING SYSTEM Often grown as an irrigated garden crop; in wet lands, in rotation with rice, sugarcane, banana, etc. in 3-to 4-year rotations and in garden lands, in rotation with chillies, vegetables, maize, pulses, etc. Castor, pigeon pea and other "bushy" crops are often grown on the bunds of turmeric plots. Turmeric is also grown as an intercrop in plantations of fruit trees and other perennial agricultural species.

PROPAGATION Propagated by finger or rhizomes 4 to 5 cm long and having at least one sound eye-bud; sometimes sprouted under moist straw before sowing.

LAND PREPARATION The land should preferably be thoroughly prepared; organic matter is added at the time of last ploughing. Often planted in beds, or on ridges, which are prepared after the final ploughing.

SOWING, SPACING, SEED RATE The rhizomes are planted about 7.5 cm deep; if planted on ridges, one or two rows per ridge, ridges 30-45 cm apart and 20-30 cm between plants; closer spacing gives higher yields. If planted on beds, 20-30 cm between plants in either direction. Depending on the spacing adopted and the extent of mixed cropping, seed rate varies from 1,000-2000 kg/ha. In India, the crop is best planted in April or May, and a leaf mulch is provided, especially if planted in beds.

AFTERCARE Leaves appear 3-4 weeks after planting. Weeding, usually by hand, and earthing-up are done three or four times. Good response to manuring; usually only organic manures and potash are given, but of late, fertilizers especially N and K are recommended, at the rate of 80 kg N and 80 kg K_2O per hectare. A part of N is given at the time of planting and the rest as top-dressing at the time of earthing-up.

HARVESTING The crop planted in April-May will be ready for harvest in December-January when the leaves turn yellow and begin to dry. Harvesting is by digging, and can be staggered according to convenience. A portion of the crop can be kept unharvested to supply seed for the next crop.

PROCESSING The leaf stalks and roots are removed, and the primary tubers are separated from the rhizomes; the former are sometimes split before processing. For immediate local use, fresh rhizomes can be used. Others are "softened" by boiling in water for about 30 minutes. Then they are dried in the sun for 10-15 days. The bits of adhering roots and scales are removed by hand and the dried produce is polished by rocking in suspended bamboo baskets containing small granite stones. Raw turmeric yields 18-25% of the dried produce, which is then graded as bulbs or rounds and splits and fingers for marketing.

YIELD

Yields are variable, ranging from 15 to 25 tons of "green" or raw turmeric per hectare. Under good management, yields up to 40 tons/ha can be obtained.

PESTS AND DISEASES

The shoot-boring caterpillar *Dichocrosis punctiferalis*, and the fungi *Taphrina maculans* and *Colletotrichum capsici* which cause leaf spots, are the major enemies of the crop.

AGROFORESTRY POTENTIAL

The shade-tolerant nature and relative ease of management of the crop make it a good species for agroforestry.

MAJOR RESEARCH INSTITUTIONS AND REFERENCES

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OTHER CROPS

ARECANUT

SCIENTIFIC NAME	*Areca catechu* L.
	Family *Palmae*
	2n = 32
COMMON NAMES	Areca or betel palm (E)
	Arec cachou, aréquier (F)
	Areca, palma catecú (Sp)

USES AND ECONOMIC IMPORTANCE

Arecanut is a masticatory, chewed with betel (*Piper betle* L.) leaves and a little slaked lime. Sometimes other substances like cardamom, clove, tobacco etc. are also added to the quid. Chewing of arecanut causes continuous salivation and is believed to make teeth and gums strong, and also to help digestion. Arecanut is also grown as an ornamental plant.

ORIGIN AND DISTRIBUTION

Arecanut is believed to be a native of South or Southeast Asia, and its cultivation is confined mainly to India, Bangladesh, Sri Lanka, Malaysia and Indonesia. India has the largest area and production of the crop.

PLANT CHARACTERISTICS

Arecanut is a slender, delicate, erect tropical palm that attains a height of about 25 m and lives for 60-100 years. Adventitious roots are produced from the bole; primary roots, about 1.5 cm in diameter, branch to give secondary and tertiary roots. Roots are mostly confined within a radius of 1 m from the bole and in the top 60 cm of soil. Stem is unbranched, cylindrical, straight, 25-40 cm in diameter, about 25 m tall, ringed with leaf scars, and has a crown of leaves at the tip. The crown is about 2.5 m in diameter; leaves 1.0-1.5 m long with a smooth sheathing base that completely encircles the stem. Leaves are retained for about two years after unfurling; mature crown contains about 12 functional leaves.

Flowering begins 4-6 years after planting; every leaf axil produces an inflorescence and is protected by the leaf sheath until emergence. A few inflorescences abort and an average of 3-5 bunches are produced annually.

The spadix is enclosed by a double boat-shaped spathe, about 60 x 18 cm. The rachis is 30-60 cm long with 20-25 secondary branches which bear tertiary branches. Flowers are unisexual; male flowers are numerous, minute and deciduous and are borne above female flowers. Female flowers are borne in the base of secondary and tertiary branches, 200-500 per spadix.

Male flowers open first, and shed off completely in 2-4 weeks; the maximum dispersal of pollen is between 9.00 and 12.00 in the forenoon. Female flowers open later and remain receptive for 3-4 days. Pollination is mostly by wind. The first inflorescences on young palms produce only male flowers.

The fruits mature 8-10 months after pollination. All female flowers do not set fruits, and one spadix produces 50-400 fruits. The fruit is a fibrous drupe, variable in size and shape, green when unripe, turning yellow-to-orange when ripe. The seed, wrongly called "nut", is ovoid or ellipsoidal, and weighs 10-20 g. The endosperm, which is the edible portion, is hard in texture and pale brown in colour.

Various types of areca have been described based on physical characteristics, and cultivators classify them according to the length of time taken for maturity, compactness of the inflorescence, etc. A few high-yielding, early-bearing types have been developed in India.

ECOLOGY

CLIMATE Areca grows well in regions of heavy, well-distributed rainfall or assured moisture supply (by irrigation). Cultivation extends over areas of 1000-5000 mm annual rainfall, and from sea level to 900 m altitude. The optimum temperature range is 16-35^{o}C.

SOIL Grows well in well-drained laterite or reddish soil, fertile clay loams and alluvial loams. Grows very poorly in ill-drained soil.

PHYSIOLOGY AND COMPOSITION

Areca prefers a cool and shady atmosphere for protecting its stem against sun scorching; however the crown should be exposed to full sunlight. It does not withstand drought or waterlogging.

The endosperm contains 0.2-0.7% alkaloids, the most important being arecoline, $C_8H_{13}O_2N$. It also contains 11-25% of catechol tannins, the content of which is reduced during ripening, and about 47% carbohydrates, 30% water, and 5% each protein and fat.

AGRONOMY

CROPPING SYSTEM Usually grown among other fruit trees which provide the required shady and cool environment. Also grown with pepper, cardamom, etc. When young, areca plants are usually grown in the shade of bananas. A number of annuals, especially tubers, are also grown as intercrops.

PROPAGATION By seeds; seedlings are usually raised in a nursery. Mature nuts of good size and shape are selected from healthy palms, dried in the shade for 3-4 days, and sown shallow 10-20 cm apart, in raised nursery beds during March-May. The nursery is watered regularly and provided with suitable shade. In some places, seedlings are transplanted to a second nursery when they are 9 months old.

LAND PREPARATION The land is well-prepared by repeated ploughings and water channels and drains are provided according to requirements. Sixty cubic cm planting pits are filled with a mixture of earth and compost.

PLANTING Healthy robust seedlings are usually transplanted when they are a year old; seedlings are sometimes retained in the nursery for 2 years. Usual spacing is 2.7 x 2.7 m, i.e. about 1300 plants/ha. But spacing will vary depending upon the intercropping proposed. Seedlings sometimes are underplanted in 20-year-old or older areca gardens.

MANURING Regular manuring with organics and inorganics is customary in certain parts. Green leaves, cattle manure etc.

are applied to the basins around the palms or to trenches near the bases. General fertilizer recommendation is 100 g N, 40 g P_2O_5 and 140 g K_2O per palm annually in two splits in September-October and March-April.

AFTERCARE The plantations are hoed and weeded twice a year. Draining of surplus water in heavy rainfall seasons and irrigation during dry periods are essential.

HARVESTING Bearing commences 6-10 years after planting and full production about 8 years afterwards. Sometimes immature nuts are harvested during July to December, but mostly the nuts are harvested when ripe, from December to May. Trained labourers climb up the palms and pluck the bunches that are ready. They move from one palm to another by bending the palms, without descending to the ground.

CURING AND PROCESSING The nuts are separated from the stalk and the husk is removed; then the endosperm is cut into four pieces or shredded into smaller pieces and boiled for 2-3 hours in water containing the pounded bark of aromatic plants (to impart colour), in a copper vessel. The nuts are then taken out with perforated ladles and dried in the sun or artificially for 6-7 days.

PESTS AND DISEASES

The major pest is the spindle bug, *Carvalhoia arecae*, which sucks the juice from the unopened spindles.

The fungus *Phytophthora palmivora* causes the serious disease fruit rot, causing immature nut fall. Regular sprayings are recommended with 1% Bordeaux mixture during breaks in the rainy season. Other fungal diseases also cause considerable damage.

In recent years, a yellowing disease of unknown aetiology has affected the palms in India. It causes a considerable decline in vigour and productivity.

Sun-scorching causes drying of the affected parts and splitting and bending of the stem. To prevent this, it is usual either to interplant other plants with medium-height canopy, or to plant them around the garden as border rows.

AGROFORESTRY POTENTIAL

Areca is a plant of potential value for agroforestry because of its amenability to combination culture. However, it is not suited for marginal or dry areas and prefers to have intensive care.

MAJOR RESEARCH INSTITUTIONS AND REFERENCES

Central Plantation Crops Research Institute (ICAR) Regional Station, Vittal, Karnataka, India.

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OTHER CROPS

CASHEW

SCIENTIFIC NAME

Anacardium occidentale L.
Family *Anacardiaceae*
2n = 42

COMMON NAMES

Cashew	(E)
Anacardes	(F)
Acajú	(Sp)

USES AND ECONOMIC IMPORTANCE

An important cash crop, grown mainly for the highly-priced kernels which are used in confections and desserts all over the world. Cashew-shell oil, which is obtained from their shells or pericarps, is also valuable and is used for a number of industrial purposes such as paints and varnishes, inks, brake-linings, etc. The juicy cashew apple is edible, and the juice may be fermented and made into a wine, or distilled to make a liquor.

ORIGIN AND DISTRIBUTION

Cashew is a native of tropical America, including Brazil and the West Indies. It is now widely distributed throughout the tropics. The main producing countries are India, Mozambique, Tanzania and Brazil.

PLANT CHARACTERISTICS

A spreading, evergreen, tropical tree that grows to about 12 m; old trees commonly have canopies of up to 12 m diameter. Roots penetrate to considerable depth and also spread horizontally to an area twice that of the canopy.

Leaves are alternate, simple and obovate; lamina 10-20 x 4-12 cm. Inflorescence is a lax panicle, produced on new shoots of current season's growth, about 25 cm long, consists of many sweet-scented, small flowers; male (about 85%) and hermaphrodite (the remainder) flowers are present in the same inflorescence. An inflorescence contains about 60 hermaphrodite flowers, about 30% of which are pollinated; mostly cross-pollinated; pollination by insects; there is a considerable amount of immature fruit drop both for physiological reasons and as a result of pest attack; less than 10% of the hermaphrodite flowers produce mature fruits (3-5 per inflorescence). Fruit is a kidney-shaped nut (achene) about 3 x 2.5 cm with a hard shell (pericarp). The cashew apple is an enlarged pedicel; it is shiny, juicy, thin-skinned, has an astringent taste, is red (or yellow) in colour when ripe, 10-20 x 4-8 cm.

Bearing commences about 3 years after planting, full production in about 10 years; trees continue bearing until they are about 50 years of age.

No distinct varieties have been identified; but there is considerable variation among the trees produced from seedlings.

ECOLOGY

CLIMATE Cashew is grown under a wide range of climatic conditions varying from 50-375 cm annual rainfall and from sea level to about 1300 m altitude. However it prefers lower altitudes. Cashew is hardy and drought-resistant. Flowering and fruit-set take place during dry weather; rain during this period causes withering of flowers, fungal diseases, and darkening of the developing nuts. Cashew does not tolerate frost.

SOIL Cashew grows under a wide range of soil conditions. It grows satisfactorily on relatively infertile and rocky areas that are unsuitable for other crops.

PHYSIOLOGY AND COMPOSITION

Cashew requires good drainage, it prefers a dry period for good flowering and fruit set, and it grows in rocky, sloping, and infertile soils; thus it is an ideal species for marginal lands.

The nuts contain 20% protein; 45% fat; 26% carbohydrate, 5% water and 2.5% minerals. The shell (pericarp) contains approximately 50% cashew-shell oil, which consists of 90% anacardic acid and 10% cardol. The cashew apple contains about 12% carbohydrate and is rich in vitamin C.

AGRONOMY

Grows scattered in marginal lands or is cultivated on a plantation scale; also sometimes mixed with other tree crops in the homestead such as mango, jackfruit, coconuts, etc. Intercropping with cassava, maize, bananas and similar crops can be done during the 3-4 years of growth until the canopy nears closure and the roots spread out. Cattle grazing can be practised in mature plantations.

Propagation is usually by seeds which are sown at stake *(in situ)* 5-8 cm deep, in planting holes about 30 cm wide. Germination is slow and usually occurs 2-4 weeks after sowing. Because of poor and slow germination, three seeds are usually planted per hole, and after germination and establishment, only one is retained. Nuts with high specific gravity (and which sink in water) germinate fast and establish well. Cashew can also be propagated vegetatively by layering or grafting. Usual spacing is 9 x 9 m with thinning after five years to a lesser plant density. After establishment, very little aftercare is needed for cashew. The trees are shaped by removing the lower branches to allow nut collection and human movement. When established on a plantation scale, the undergrowth may be checked by slashing or cattle grazing.

Manuring is not usually practised, but recent trials in India have shown good response to N and K fertilizers, which may be applied annually at the rate of 500 g N and 640 g K_2O per tree. Nitrogen can also be given as a foliar spray along with insecticides.

Bearing commences in the third year after planting; full production in 7-10 years. The nuts are harvested by picking them from the ground where they fall. In good weather, the nuts can be collected from the ground once a week, but in rainy seasons, they have to be collected every day to prevent discolouration. When the nuts are ripe, as indicated by the size and colour of the apple, they can also be harvested with a sickle tied to the tip of a long bamboo or other light wooden pole, to prevent damage by birds. The birds, attracted by the ripening apples, scatter the nuts at a distance from the trees after sucking the juice of the apple. The nuts may be removed from the apple immediately after harvesting and dried in the sun for 2-3 days.

The dried nuts are roasted either in open pans over a furnace or in rotary cylinders and oil baths. Shelling is done by hand soon after roasting. The kernels are dried in the sun or in hot-air chambers, and are later packed in tin cans under vacuum.

YIELD

Yield per tree varies considerably, ranging from 1-20 kg per year. In well-managed plantations, the annual yield is 800-1200 kg/ha.

PESTS AND DISEASES

The major pest is the "tea mosquito", *Helopeltis* spp., which sucks tender parts of the inflorescence and causes black lesions in the affected parts and considerable flower drop. It is also responsible for inflorescence blight. Two insecticidal sprays during the time of flower emergence reduce the extent of damage.

AGROFORESTRY POTENTIAL

Cashew is a very promising tree crop for agroforestry because of its ecophysiological adaptations mentioned earlier.

MAJOR RESEARCH INSTITUTIONS AND REFERENCES

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OTHER CROPS

CINCHONA

SCIENTIFIC NAME	*Cinchona* spp.
	Family *Rubiaceae*
COMMON NAMES	Cinchona, Quinine (E)
	Cinchone (F)
	Quino (Sp)

USES AND ECONOMIC IMPORTANCE

Before World War II, the alkaloid quinine obtained from the bark of the cinchona plant provided the most important anti-malarial drug in both prophylactic and curative treatments of the disease. Now it has lost much of its importance because of the fall in incidence of malaria and the development of synthetic anti-malarials. Cinchona is also used as a tonic and antiseptic and for minor pharmaceutical uses.

ORIGIN AND DISTRIBUTION

Cinchona existed in the Andean region of South America from early times. It is believed that it was introduced from there to South and Southeast Asia and Africa. During the pre-war period, Indonesia (mainly West Java) accounted for about 90% of the total world production. Also grown in India, Sri Lanka, East Africa and South America.

PLANT CHARACTERISTICS

Evergreen shrubs or trees. Leaves opposite, simple, deciduous. Inflorescence is a terminal panicle; flowers are small and fragrant. Cross-pollinated by insects, mainly bees. Fruit is a capsule, bursting open from base upwards and having 40-50 small, winged, flat seeds.

There are four main economic species:

1. *C. calisaya* (2n=34). Large tree with stout, straight trunk; occurs in Peru and Bolivia at 1000-1500 m altitude. Also grown in India at 400-900 m altitudes.

2. *C. ledgeriana* (2n=34). Weak, profusely-branching, quick-growing tree; 6-16 m height. Flowers at the end of the rainy season in Java and fruits ripen in about 8 months. Bark thick and brown; yields the Ledger Bark of commerce. Clones giving 14-16% quinine have been evolved. All cinchona in Indonesia is of the ledgeriana type; also grown in India at 1000-2000 m altitude.

3. *C. officinalis* (2n=34). Slender tree, 6-10 m tall; indigenous to altitudes of 200-300 m in Colombia and Peru, often in montane forest. Rough brown bark yields the crown or Loxa bark of commerce, poor in quinine content; not grown commercially.

4. *C. succirubra* (2n=34). Large, erect, rapidly-growing tree to 30 m height, sparsely branched but sheds lower branches. Grown from Costa Rica to Bolivia from 1000-3500 m altitude. Its brown bark with a few whitish markings is a source of the red bark of commerce, but it is difficult to extract quinine. Used as a root-stock for grafting with *C. ledgeriana;* grown in India from 600-2000 m altitude.

In addition to these, a number of hybrids involving the above have been produced:

C. hybrida=C. ledgeriana x *C. succirubra*
C. robusta=C. officinalis x *C. succirubra*

ECOLOGY

CLIMATE Cinchona's optimum climatic requirements are at high altitudes in the tropics with fairly high rainfall (well-distributed annual rainfall of about 250 cm) and average minimum and maximum temperatures of 14°C and 21°C. At low elevations and limited soil moisture supply, alkaloid content is reduced.

SOIL Grows best on light, well-drained, forest soils rich in organic matter, and having pH above 5.0. It grows poorly on soils where the vegetation was burned off when preparing land for planting.

PHYSIOLOGY AND COMPOSITION

Cinchona does not tolerate waterlogging; growth is very poor below 8°C and above 27°C.

The most important among the nearly 30 alkaloids isolated from cinchona is quinine ($C_{20}H_{24}N_2O_2$). The alkaloids occur in the bark of the roots, trunks, and branches; roots have the greatest content and branches the least. The alkaloid content is affected by environmental conditions, species and genotype. *C. ledgeriana* in Java contains 4-13.5% quinine in the stem bark.

AGRONOMY

CROPPING SYSTEM Best growth of cinchona is obtained when it is grown as a first cycle crop in new forest clearings.

PROPAGATION Usually from seeds; seeds require light for germination; germination in 2-3 weeks; seeds lose viability quickly. Can also be propagated from apical stem cuttings. In Java, replanting is usually done with high-yielding clones of *C. ledgeriana* budded or grafted on to *C. succirubra* root stocks.

SOWING A nursery is raised by broadcasting the seeds on shaded seed-beds and watering with fine mist-spray. Young seedlings are transplanted to a main nursery 4-5 months after sowing (when they will be about 5 cm tall with 2-3 pairs of leaves) at 10-15 cm spacing. Budding or grafting, when vegetatively propagated, is also done in the nursery. Planting in the main field is done when seedlings are 1-2 years old and 30-50 cm high.

SPACING, AFTERCARE Usual spacing in the main field is 1.3 x 1.3 m. Saplings are pruned to obtain a single stout stem. Cinchona requires a good supply of nitrogen, phosphorus and lime for optimum growth and a better yield of bark in terms of both quantity and quinine content.

HARVESTING Harvesting begins the fourth year after planting and the plants are selectively thinned annually to approximately 25% of the original stand density, which is finally unrooted after 8-12 years. The bark has the maximum quinine content when the plants are in the final harvesting stage (8-12 years old). The harvested plants are cut into suitable lengths of stems, roots and branches, and are beaten to detach the bark from wood. The bark is peeled off and dried in the sun or hot-air kilns from the original 70% moisture to 10%.

YIELD

An average yield of 5-8 kg dried bark is obtained per mature tree with a quinine content of 1-2.5 g/dm^2, and a total of 150-250 g quinine per tree. With about 1500 trees per ha at final harvesting, and an average yield of 1.5 g quinine sulphate per 1 g quinine, the yields of quinine sulphate per hectare will be 300-500 kg/ha, which is a high yield. Under normal conditions, the yield is about 150 kg quinine sulphate per ha.

PESTS AND DISEASES

Damping off of seedlings in the nursery, caused by *Rhizoctonia solani* and other fungi; root rot of transplants caused by *Armillaria* spp.; and the insect pest *Helopeltis* spp., are the major hazards.

AGROFORESTRY POTENTIAL

Cinchona is a good species for cultivation in the sloping and mountainous highlands of the humid tropics.

RESEARCH INSTITUTIONS AND REFERENCES

Owing to the decline in the importance of cinchona, not much research is now being done on the crop.

PYRETHRUM

SCIENTIFIC NAME	*Chrysanthemum cinerariaefolium* (Trev.) Bocc. syn. *Pyrethrum cinerariaefolium* (Trev.) Family *Compositae* 2n = 18
COMMON NAMES	Pyrethrum (E) Pyrethrum (F) Piretrina (Sp)

USES AND ECONOMIC IMPORTANCE

Pyrethrum, the insecticide, is obtained mainly from the flowers of *C. cinerariaefolium*. *C. coccineum* was the original source in Persia, but its toxicity is lower. In spite of the modern chlorinated hydrocarbons and organo-phosphorus insecticides, pyrethrum still maintains its status as an effective insecticide against a broad range of insects with little development of resistant strains and low toxicity to mammals. It is non-inflammable and leaves no oily residues. The active ingredient is pyrethrin (1.0-1.3% in dried flowers).

ORIGIN AND DISTRIBUTION

Wild strains are found on the Dalmatian coast of Yugoslavia. It was introduced into Japan and Europe in the late 19th and early 20th century. Introduced into Kenya in the late 1920's, that country is now the leading producer (2/3 total world production) with an annual production of 12,000 tons of dried flowers. Now also cultivated in Tanzania, Uganda, Ecuador, Brazil, New Guinea and India.

PLANT CHARACTERISTICS

Tufted perennial herb, 30-60 cm high. Young plants have a rosette habit. Roots many and fibrous. Leaves alternate, 10-30 cm long including slender long petiole. Capitula 3-4 cm in diameter, borne singly on long, slender peduncles. Pyrethrum is self-fertile; it must be cross-pollinated to produce viable seed, usually by insects. A few high-yielding cultivars giving a higher yield of flowers as well as higher content of active principle have been evolved in Kenya.

ECOLOGY

CLIMATE Pyrethrum thrives best in areas of 80-120 cm per year of evenly distributed rainfall. In the tropics, flowering and high pyrethrin content are obtained only at high altitudes - 1800-2500 m in Kenya. Pyrethrin content is also higher in areas with low mean annual temperatures (up to 13°C). In Kenya, flowering starts in May and reaches a maximum from September to January. Monthly rainfall of up to 15 cm is good.

SOILS Well-drained loams are the best suited. Cannot withstand waterlogging. In Dalmatia, pyrethrum is grown on calcareous, slightly alkaline soils.

PHYSIOLOGY AND COMPOSITION

Chilling (about 10 days at or below 15°C) is necessary to stimulate flower bud development.

The insecticidal property of pyrethrum is due to the substances pyrethrin I, pyrethrin II, cinerin I and cinerin II, collectively known as pyrethrins. Pyrethrin I has the greatest toxicity. Kenyan pyrethrum contains a minimum of 1.3% pyrethrins with a high proportion of pyrethrin I. The pyrethrin content is greater at higher altitudes.

AGRONOMY

CROPPING SYSTEM Usually grown in rotation with wheat, maize, grass leys, etc. A crop of pyrethrum is normally retained for three years and then it is replaced by other crops in rotation. Therefore, to maintain the area under the crop, it is necessary to re-plant one-third of the total area every year.

PROPAGATION From seed; sown thinly in the nursery and lightly covered with soil and kept moist under shade. Seedlings transplanted when about 4 months old and 10-12 cm high.

SOWING, SPACING Seedlings planted in rows along the contours at 90 x 30 cm; a good stand is important for which gap-filling should be done as soon as possible. Ridge planting is recommended. On non-mechanized farms double rows of 30 x 30 cm with 90 cm in between two pairs of rows are also common.

NUTRITION Manuring does not influence pyrethrin content, but phosphorus application increases the yield. Usually 150-250 kg triple superphosphate per ha is applied and the effect lasts over 2-3 seasons. N and K have not been found to increase yields. A basal dressing of bulky organic manures is recommended.

AFTERCARE Weeding is very important. Mulching between the rows especially in dry seasons, and irrigation during the dry spells are beneficial.

HARVESTING By hand-picking, usually by women and children. First picking is about 4 months after planting and thereafter at intervals of 2-3 weeks during the flowering period, which extends over 9-10 months in Kenya. The fully expanded flower-heads are harvested when the outer 4-5 rows of disc florets are open. An experienced picker can harvest up to 25 kg fresh flowers in a day.

PROCESSING Harvested flowers are spread on trays and dried in special driers in which there is an upward draught of hot air passing over hot flues. In 6-8 h, the moisture content is reduced from about 80% to 8-10%. Fresh flowers should not be heaped; if heaped, they will start fermenting. Dried flowers are marketed as bales, or as an extract containing 25-30% pyrethrins.

YIELD

About 200 kg/ha of dried flowers in the first year, and 800-1000 kg/ha during the second and third years at 2500 m elevation; yields are much less (300-400 kg/ha) at lower altitudes.

PESTS AND DISEASES

Pyrethrum thrips, *Thrips nigropilosus*, which damage the leaves, and *T. tabaci*, which damage the inflorescence, are the serious pests. The bud disease caused by the fungus *Ramularia bullunensis* affects the buds, causing discolouration and distortion of the flowers developed from affected buds.

AGROFORESTRY POTENTIAL

Pyrethrum is a good crop in tropical highlands with no pronounced dry seasons. It is usually grown mixed with, or in rotation with, other agricultural species in areas interspersed with trees.

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OTHER CROPS

RUBBER

SCIENTIFIC NAME	*Hevea brasiliensis* Muell. - Arg. Family *Euphorbiaceae*
COMMON NAMES	Para rubber (E) Caoutchouc (F) Caucho (Sp)

USES AND ECONOMIC IMPORTANCE

It has been estimated that some 50,000 different products are made from rubber directly or indirectly. About 70% of total rubber consumption is for the manufacture of tyres and tubes, about 6% for footwear, and about 4% for wire and cable insulation. Rubber powder with bitumen is used for road surfacing. Synthetic products and the increasing use of plastics pose competition to natural rubber. The kernel, which constitutes 50-60% of the seed, contains 40-50% of a semi-drying oil, and the cake after oil extraction contains about 30% protein.

ORIGIN AND DISTRIBUTION

Para rubber is a native of the rain forests of the Amazon basin. It was introduced about a century ago to Malaya, which now accounts for 92% of the world's natural rubber. Other producing countries in Asia are Indonesia, India, the Philippines and Sri Lanka. Africa accounts for 7% of world production, Nigeria, Liberia and other West African countries being the main producers. Brazil, the natural home of the crop, accounts for less than 1% of the total production.

PLANT CHARACTERISTICS

A quick-growing, often deciduous tree up to 25 m high, with copious white latex in all parts. The tap-root is well-developed, with long, branched laterals. Trunks are tapering from the base in trees raised from seedlings, and cylindrical in trees raised from buddings. In saplings, leaves appear in tiers. The latex vessels are modified sieve tubes and are arranged in concentric cylinders in a counter-clockwise direction at about 3.5° to the vertical. The number of vessels per ring and number of rings vary with age and thickness of the bark. The bark is usually 10-11 mm thick. The bark that is removed by tapping will be renewed in 7-8 years.

Leaves are trifoliate and spirally arranged. Petioles vary in length from 2-79 cm, though usually are 15 cm. Lamina is usually 15 x 5 cm, but varies. Young leaves are purple bronze in colour and turn green and brittle on hardening and orange-yellow or red before falling. In Malaya, a 'wintering' occurs when the leaves are shed after the dry weather at the beginning of the year, and new leaves are then produced.

Inflorescences are many-flowered axillary panicles borne on the basal part of new flush. Flowers are small, scented and unisexual. Female flowers are larger, at the terminal ends of main and lateral branches; male flowers are many, 60-80 per each female flower, and smaller.

Flowering lasts over 2 weeks. Only very few of the female flowers set fruits, which ripen 5-6 months after fertilization. The fruit is a 3-lobed capsule, 3-5 cm in diameter with 1 seed per carpel; seeds are large (3 x 2 cm), shiny, and weigh 2-4 g. Pollination is entomophilous, mainly by midges and thrips. Some clones are self-incompatible.

Considerable progress has been achieved in rubber breeding (by hand pollination) and several high-yielding clones have been developed. They are mostly known after RRIM (Rubber Research Institute of Malaysia), or private plantations like Glenshiel (GL), Prang Basar (PB) etc.

ECOLOGY

CLIMATE Rubber is grown mostly between 15°N and 10°S latitudes in low altitudes (up to 300 m) having a hot, humid and equable climate with temperature ranging from 23 to 35°C, and a well-distributed rainfall of 180-250 cm per annum. Wide temperature ranges and pronounced dry periods are not preferred.

SOIL In the native habitat, rubber trees are found growing in swampy areas, but cultivated plantations do best on deep, well-drained loamy soils with pH 4.5 to 6, and moderate fertility.

PHYSIOLOGY AND COMPOSITION

The tree does not tolerate prolonged drought. Production of latex is stimulated by application of hormones, the one used widely being ethryl.

The latex consists of a colloidal suspension of rubber particles (30-40%) in an aqueous serum.

Rubber is a hydrocarbon, cis-1, 4-polyisoprene, $(C_5H_8)_n$. It is manufactured in the plant from carbohydrates, but its exact function in the plant is not known. Latex also contains proteins, resins, sugars, glucosides, tannins, alkaloids and mineral salts.

AGRONOMY

CROPPING SYSTEM Rubber is normally grown on a plantation scale, but when planting rubber on any but good soils on level grounds, leguminous cover crops are strongly advocated. Rubber is also grown on small holdings; in Malaysia, about 70% of the total area under rubber and 60% of total production are accounted for by small holdings of less than 4 ha. On most small holdings, intercropping is practised for the first 3-5 years. In some countries, rubber is planted at wider spacings with permanent mixtures of crops like coffee and cacao.

PROPAGATION Earlier plantations were raised from seed. Seeds remain viable for a short time (one month) after collection and germinate 3-25 days after sowing. Even now seedling rubber is established in sizeable areas. Seeds are first germinated in shaded nurseries, with friable soil, coir dust, or sand, and after three weeks, the germinated seeds are planted in nurseries at 30 x 30 cm spacings. One hectare of nursery will give approximately 25,000-30,000 seedlings of the required size for pulling out when 10-15 months old, for planting in the field.

In recent years, budding has been used widely for propagation of rubber, especially by progressive planters. By this method, it has been possible to raise plantations with a high latex yield. The stock plants are raised in nursery, and then can be budded when they attain about 8 cm girth at about 8 cm height from the ground. The bud is taken in about three weeks and the budded stocks can be stumped 6-7 weeks after budding. In stumped budding, the scion is allowed to remain in the nursery for 12-18 months after budding. Crown budding is also practised, mostly to produce a disease-resistant crown on a high-yielding frame.

In recent years, the use of 'clonal seeds' obtained from good monoclonal plantations or from a mixture of high-yielding poly-clones is becoming popular. But the clonal seedlings are more variable than budded rubber and selective thinning of close plantings is adopted to improve production.

PLANTING If a forest area is cleared for planting rubber, all commercial timber is removed and the stumps are removed along the lines or contours of the proposed planting. It is usual to burn the original growth to establish cover crops.

Closer plantings give lower yields per tree and per tapper, but higher yields per hectare. Optimum planting density is based on a compromise between yield per tree and output per tapper. Of late, the practice is to plant more plants initially, 375-450 buddings or 500-600 seedlings per hectare, to be thinned down finally to 250-300 per hectare in two stages, one when three years old, based on girth, and later after the next 3 years, based on the initial yield. Planting distances are 4.5 x 4.5 m for buddings and 4 x 4 m for seedlings; also used are rectangular plantings of 9 x 2 m.

AFTERCARE Care of seedlings and maintenance of the leguminous cover are the major operations during the pre-tapping period. The usual cover crops are *Calopogonium mucunoides* Desv., *Centrosema pubescens* Benth. and *Pueraria phaseoloides* (Roxb.).

MANURING Response to manuring depends upon soil type, cultivation practice (cover crops), yield level, etc. Nurseries usually receive NPK fertilizers. Potassium and magnesium deficiencies are usually widespread. A general fertilizer dose consists of 120-140 g N, 110-140 g P_2O_5, 160-210 g K_2O and 70-100 g MgO per adult tree per year.

TAPPING The latex vessels are more numerous near the cambium; therefore it is necessary to make the cut as near the cambium as possible. Because the latex vessels are disposed vertically at a slight angle (3.5^{o}) to the right, the tapping cut slopes down to the right. The latex flows along the cut and then down a vertical guide line at the base of which a metallic spout is fixed which directs the latex to a cup (usually half a coconut shell). The amount of bark removed at each tapping should be minimal to re-open the vessel, at an average of 25 cm per year for alternate daily tapping.

The usual tapping is s/2.d/2 (indicating a half-spiral tapping cut with tapping in alternate days) and this is referred to as 100%; s/2.d/1 is 200%. Trees are rested for some time, usually at 'wintering' and during heavy rains; e.g., 6m/9 means the tree is rested for 3 months after 6 months of tapping.

Tapping begins at 6-6.30 a.m. One tapper can tap about 400-500 trees between 6 a.m. and 9 a.m.

Trees attain tapping age in 5-7 years after field planting, when about 70% of trees will have attained a girth of 50 cm at 125-150 cm height from ground. Usually the bark renewal takes place in about 10 years. The second panel is opened at the opposite side of the first panel. Yields drop markedly in second renewal bark. When rubber is to be replanted, a slaughter or intensive tapping is done for three years.

PROCESSING The latex, if not taken immediately to the factory, is prevented from coagulating by adding 10-25% ammonia. In the factory, the latex is strained and rubber content is estimated by special hydrometers for specific gravity measurements. For preparation of smoked rubber, the latex is diluted to 12-15% rubber by adding water and is poured into coagulating tanks where acetic or formic acid is added (one part of 4% formic acid to coagulate 100 parts of latex diluted to 12% rubber). The rubber coagulates as a soft whitish mass, which is taken out and passed through grooved rollers to produce a corrugated or ridged surface. The sheets are then dried in a smoke house for four days at 50-55^{o}C temperature, and then graded and packed in bales.

Crêpe rubber is produced by passing the coagulated sheet rubber through special rollers running at unequal speeds. Drying is done in smoke-free houses.

YIELD

Average yield of unselected clones is about 500 kg/ha, and of budded clones about 1000 kg/ha (dried rubber). Modern clones yield about 2000 kg/ha in commercial, estate production.

PESTS AND DISEASES

Rubber is affected by a number of fungal diseases, the more serious being black stripe or leaf blight, *Phytophthora palmivora;* powdery mildew, *Oidium heveae;* pink disease, *Corticium salmonicolor;* and South American leaf blight, which is the major limiting factor to rubber production in South America, caused by *Microcyclus ulei.* Plant protection by fungicidal sprays is a routine operation in rubber estates.

Rubber is relatively less attacked by insect pests than by fungal diseases. Nutritional disorders also cause disease-like symptoms.

AGROFORESTRY POTENTIAL

Most of the rubber plantations have been established in cleared forest land; of late, rubber is being taken up as a smallholder crop, and in such cases, intercroppings of various intensities and forms are practised. Leguminous cover crops, which form an essential part of rubber cultivation when intercropping is not practised, provide protection to soil and build up soil fertility. Thus, rubber cultivation presents a good form of agroforestry.

RESEARCH INSTITUTIONS AND REFERENCES

Considerable research has been undertaken on various aspects of rubber, and almost all the Asian rubber-producing countries have rubber research institutes. The foremost among them is the Rubber Research Institute of Malaysia (RRIM).

The various publications of RRIM, including the Annual Report, Journal (published quarterly) and the Planters' Bulletins (published bimonthly), are the major reference materials.

Fig. 34. Two year-old budgrafted rubber trees intercropped with banana (Photo credit: Rubber Research Institute of Malaysia).

PART III

SHORT NOTES ON SOME UNDEREXPLOITED AND LOCALIZED SPECIES

FOOD CROPS

BAMBARA GROUNDNUT

Voandzeia subterranea (L.) Thou.
(Leguminosae - Papilionoideae)

Bambara groundnut is an important local African pulse crop, and like the groundnut plant, *Arachis hypogaea* L., it produces its fruit under the soil. The ripe seeds contain about 60% carbohydrate, 18% protein and 6% fat. It is indigenous to tropical Africa and is mainly grown there, but it is also found in Asia, and parts of South and Central America.

The plant is a branched, herbaceous, annual legume with a creeping, almost submerged, much-branched stem approximately 10-15 cm in length. Rooting takes place at the nodes and the internodes are very short, giving a bunchy appearance. Leaves are pinnately trifoliate with long, erect, grooved petiole. Inflorescence is axillary, usually 2-flowered; flowers are usually self-pollinated. After fertilization, the gynophore elongates and pushes the ovary into the soil where the pods develop. Pods are 1-2 cm in diameter and contain one or more hard seeds. There are several types of bambara groundnut.

Bambara groundnut prefers a hot climate with an average day temperature of 20-28°C. It is usually grown in poor soils that are unsuitable for *Arachis hypogaea* L. It is adaptable to a wide range of conditions, in elevations up to 1500 m.

The crop is propagated by seed, and is usually intercropped with cereals such as pearl millet, other legumes, and cassava. Usual spacing is 10-15 cm along rows, and 45 cm between rows when grown in pure stand, for which the seed rate is 50-60 kg/ha. The rows are usually earthed up to promote fruiting.

The crop is remarkably free from pests and diseases. It matures in 4 months, and is harvested by pulling up the entire plant. Average yield is about 700 kg/ha; yields over 3000 kg/ha have also been reported.

Because of its adaptability to grow on poor soils under a wide range of conditions, and its suitability for intercropping, bambara groundnut is a good species for agroforestry.

CUCURBITACEOUS CROPS

Several members of the dicotyledonous family *Cucurbitaceae* that are extensively cultivated all over the tropics for their fruits are of special importance in agroforestry. This is because of their adaptability to a wide range of conditions, their preference for shady conditions, the ability of some species to thrive on sandy and other poor soils and withstand high temperatures and low humidities, and their relative ease of management.

Most of the cultivated species are quick-growing, prostrate or tendril-climbing annuals having extensive superficial root systems, and hollow angled stems which are usually prickly or hairy and have bicollateral vascular bundles. Leaves are alternate or arranged spirally with 2/5 phyllotaxy, usually simple, broad, deeply cut and borne on long petioles. A tendril, a leafy branch, and a flower occur on the leaf axil. Flowers usually occur singly; they are unisexual, and the plants are either monoecious or dioecious. The fruit, known as a pepo, is typical, fleshy, berry-like and has a hard rind. Seeds are without endosperm, and are usually flattened.

The cultivated genera that are important for tropical agroforestry are *Benincasa*, *Citrullus*, *Cucumis*, *Cucurbita*, *Luffa*, *Momordica* and *Trichosanthes*.

BITTER GOURD — *Momordica charantia* L.

The young bitter fruits of this plant are used as a vegetable or pickled in India and Southeast Asia; they are also used in indigenous medicines. The tender shoots and leaves are used as spinach. The plant, the origin of which is unknown, is now spread all over the tropics. It is a slender monoecious annual climber with a 5-angled stem, simple tendrils, palmately lobed, medium-sized (5-17 cm) leaves, and axillary solitary flowers, about 3 cm in diameter. The fruit is 5-25 cm long, many-seeded and has numerous tubercles. Seeds are 1-1.5 cm long and lightly brownish.

Bitter gourd is usually interplanted with other vegetables and given support. Well-drained soils with medium fertility are best. The plants begin to flower about one month after planting; the first fruits are ready for picking about 3 weeks later, and plants continue to bear fruits for the following 10-12 weeks.

CUCUMBER *Cucumis sativa* L.

The fruit is popular all over the world and is eaten either as a vegetable after cooking, or as a salad before it is fully ripe. The tender vegetative parts are used as a spinach in Southeast Asia. The fruits, especially of the small-fruited cvs called gherkins, are also pickled. The plant has been in cultivation since very early times, and is believed to be a native of India. Today it is cultivated throughout the tropics and some types are also grown in temperate regions. Numerous cvs, differing mainly in their fruits, are cultivated.

The plant is a trailing monoecious annual herb with extensive and superficial root system, rough branching stems, stiff bristly hairs, unbranched tendrils, long-petioled, alternate shallowly lobed, light-green leaves, large, showy male flowers that are borne in groups of 2-3, and usually solitary, axillary, female flowers. The fruit is globular-to-oblong, depending upon the cv., with pale green flesh, and seeds are flat, white, and 8-10 mm long. Bees are the main pollinating agent.

Cucumber prefers a warm climate with mean day and night temperatures of 30°C and 20°C. It does not tolerate waterlogging; similarly, high humidity favours fungal diseases such as downy mildew. Fertile sandy loam soil with a pH of 6.5-7.5 is most suited.

Like other cucurbitaceous plants, cucumber is propagated from seeds planted on hills about 1 m apart, with 2-3 plants per hill. The crop responds well to organic manures. The fruit is picked at different stages of maturity, beginning about 2 months after planting. Average yields are 4000-6000 kg/ha.

Cucumber is also a good species for agroforestry, as it grows and yields satisfactorily under light tree canopies in a variety of conditions.

LOOFAH *Luffa* spp.

Two species of *Luffa* are grown, mainly in the East, for their tender fruits which are used as vegetables.

Luffa acutangula (L.) Roxb. is the angled loofah popular in Inida and the East; unlike other cucurbits, it grows well in the low humid tropics. It is a stout monoecious climber, with acutely 5-angled stem, hairy tendrils, and 5-7 angled, shallowly-lobed pale green leaves. Fruit is club-shaped, 15-50 x 5-10 cm. Loofahs grow better in richer soils. Fruits are harvested when they are tender; on maturity they turn bitter and inedible. Harvesting of tender fruits starts about 2 months after planting.

Luffa cylindrica (L.) M.J. Roem is commonly called smooth loofah, sponge gourd, or vegetable sponge. Loofah is the fibro-vascular network of the ripe fruit, which is used as a sponge for cleaning purposes and in the manufacture of table mats, gloves, pot holders, etc. The plant is a native of tropical Asia, possibly India, but the best loofahs are now produced in Japan. It is a vigorously climbing annual with 5-angled stem; broad, ovate, 5-7 lobed leaves; and cylindrical fruits, 30-60 cm long with light furrows or stripes. It does not grow and flower well in very heavy rains. A moderately fertile and well-drained soil is preferred. Tender fruits are harvested for use as a vegetable in India and the East, but for loofah, the ripe fruits are required, and they are harvested 4-5 months after planting. For producing loofah, the fruits are immersed in tanks of running water until the outer walls disintegrate; the seeds and pulp are then removed by washing, and then the loofah is bleached and dried in the sun.

MELON *Cucumis melo* L.

The fruits of many varieties of the vine, *Cucumis melo* are cultivated all over the world for the fresh flesh of the fruit, which is eaten out of the rind. The centre of origin of the species is unknown, and different types are popular in different parts of the world. They include:

Cantaloupes of Europe with thick yellow rind; *Musk-Melons* of U.S.A. which are smaller fruits with finely netted-to-smooth rind; *Casaba Melons* with large fruits and smooth or striped yellow rind, and melons grown in India, China, etc. which are elongated, resembling cucumber and used as a vegetable.

The plant is a trailing, softly hairy monoecious annual with large superficial root system and ridged stem. Leaves are alternate, 8-15 cm in diameter, shallowly lobed and carried on long petioles. Flowers are staminate or hermaphrodite, axillary, and solitary, and are pollinated by insects, mainly bees. Fruits vary depending upon the type. Seeds are whitish, flat, and 5-15 mm long.

The plant does well in neutral soils of the hot, dry tropics; excessive rain and humidity are detrimental; very acid soils are also not preferred. It is propagated by seed which is planted shallow, 1.5-2.0 m apart in pits, on the flat, on hills or ridges. The plant responds well to organic manures. The fruits are ready for harvest 3-4 months after planting.

Melons give best results when they receive abundant sunlight. However, they produce fairly good yields under partial shade and they are somewhat drought tolerant. Therefore, they are important species for agroforestry, especially on small farms and in backyards.

PUMPKIN, SQUASH, MARROW *Cucurbita* spp.

Several species of *Cucurbita* are cultivated throughout the tropics for their edible fruits, which are used as vegetables; however, there is considerable confusion in their commercial terminology. In general, the plant known as pumpkin, squash and marrow belong to the genera *Cucurbita*. The important species are *C. maxima*, *C. pepo*, *C. moschata* and *mixta*. All of them have originated in the Americas.

C. maxima Duch ex Lam. (Pumpkin) is a monoecious, long-trailing vine that is popular in most parts of the world. There are several types and varieties, differing mainly in the shape and size of fruits; in some varieties fruits of enormous size, weighing more than 50 kg, are produced. They are grown commonly in the drier parts of the tropics or in drier seasons in humid areas, where they yield quickly and heavily with little attention.

Fruit is soft- or hard-shelled, dull or brightly-coloured with fine-grained yellow flesh.

C. pepo L., commonly known as marrow, is widely distributed in tropical as well as temperate regions in a wide variety of forms. They prefer rather warm temperatures but are tolerant of cooler temperatures also. The stem is angular and rather prickly and the leaves are roughly triangular, somewhat deeply lobed into five rather pointed lobes. Fruits vary considerably in size and shape from long to rounded to flattened and more spherical.

C. moschata (Duch. ex Lam.) Duch. ex Poir is commonly known as pumpkin or winter squash. Since it tolerates hotter climates than other species of *Cucurbita*, it is most widely cultivated. The stem is soft, and round or smoothly angled, and devoid of prickly hairs. Leaves are large and shallowly lobed. Fruit is variable, dull in colour; flesh is yellow-to-dark orange and fine-to-coarse in texture.

C. mixta Pang. is also known as winter squash or pumpkin; it was originally included in the species *C. moschata*. It is less widely cultivated in the tropics than other species. Stems are hard and five-angled; leaves large and moderately lobed, fruit hard- or soft-shelled, dull in colour and coarse-grained.

Propagation of cucurbits is by seeds and they are usually interplanted with other crops, especially in peasant agriculture. Plants respond well to organic manuring. Mature fruits can be harvested 3-4 months after sowing, and they store well in temperatures of around 10°C.

SNAKE GOURD — *Trichosanthes cucumerina* L.
syn. *T. anguina* L.

The tender fruits of snake gourd are cooked as a vegetable and form one of the ingredients of curry.

Snake gourd is believed to be a native of Asia, and is now cultivated mainly in India and Southeast Asia, and occasionally in the West Indies. The plant is a monoecious climbing annual with a slender stem, branched tendrils and angular, 10-25-cm long leaves. Flowers are axillary, white, and solitary. Fruit is slender, 50-150 cm long and tapering, 15-25 cm in diameter. Ripe fruits are fibrous and bitter.

The crop prefers a well-drained fertile soil and warm climate: excessive rains are not preferred. They are planted over 1 m apart and trailed on to trellises. Flowering starts about 1 month after planting and a weight is usually hung to the end of the growing fruit to keep it straight. The fruit is ready for harvest about 8 weeks after flowering, and the crop dies away 6-7 months after planting. It can be grown on trellises under light-canopied trees.

WATERMELON *Citrullus lanatus* (Thunb.) Mansf
syn. *C. vulgaris* Schrad
Colocynthis citrullus (L.) O. Ktze.

Watermelon is a dessert fruit of the tropics and a preferred thirst quencher in the arid regions. The seeds contain an oil that is used as an illuminant and for cooking. The plant is a native of tropical and subtropical Africa, and is now cultivated throughout the drier parts of the tropics for local markets. There are a number of cvs with great variations in the size and taste of fruits.

The plant is a slender hairy monoecious annual with rough, angular stems and dark green, alternate, long-petioled leaves. The pale yellow flowers are smaller than those of pumpkin and squash, and they are produced singly in leaf axils. Pollination is by insects. Fruit is globose, up to 60 cm in diameter with a glabrous green or cream, mottled or striped rind.

It is cultivated mostly on fertile sands, especially on the river banks, in hot and dry areas. Propagation is by seeds which are usually planted 2-3 m apart on mounds at the rate of 6-8 seeds per mound. Fruits will be ready for harvest in 4-5 months, and peduncles are retained on the fruits while they are harvested. Fruits can be stored for 2-3 weeks. An average crop gives about 1500 marketable fruits per ha, each weighing 5-10 kg.

Watermelons prefer abundant sunshine for optimum results. However, they can be grown under trees on poor sandy soils in the drier regions where other crops seldom grow.

WAX GOURD *Benincasa hispida* (Thunb.) Cogn.

The plant is also known as white gourd or ash gourd. Its ripe young fruits are cooked as a vegetable, and as a substitute for cucumber. The seeds are fried and eaten and young leaves, vine tips, and flower buds are eaten as spinach. It is grown mainly as a household crop throughout the Asian tropics, and is little known elsewhere.

The plant is a robust, fast-growing, creeping vine resembling pumpkin vine. Three to four crops can be grown annually. It is usually planted on mounds or ridges, and trailed on to trellises, trees, or roofs. The fruit is succulent and heavy, spherical-to-oblong, about 50 x 25 cm and weighing up to 25 kg; it needs firm support. The seeds remain viable for up to 10 years and germinate in 1-2 weeks. The fruit is usually harvested in 4-5 months.

ONION *Allium cepa* L. *(Alliaceae - Liliaceae)*

Onion is one of the oldest cultivated species, and one of the most popular vegetables in the world. (It is also considered a condiment). The immature and mature bulbs, which are eaten raw, cooked, or as pickles, are the most important produce, but the green leaves are also eaten raw and used in salads.

Onion is believed to be a native of the region from the Middle East to India, and is now cultivated throughout the tropics in the drier regions, sometimes under irrigation. The major producer is the U.S.A.; Spain, Turkey, Egypt and India also produce substantial quantities.

The plant is a herbaceous biennial, usually grown as an annual. It has a very short flattened stem at the base from which shallow, fibrous roots arise. From the broadening apex of the stem, alternate glaucous distichous leaves are produced in succession, approximately one every week. The leaf blade, initially solid, later becomes hollow and emerges from the apex of the leaf sheath of the previous leaf. After some initial growth, the bases of the leaves become thickened and the innermost leaves form thickened sheath bases with aborted blades, and thus the bulb is formed. The outer leaf bases become thin and dry. When the bulb matures, no more leaves are produced; instead, the stem apex elongates into an inflorescence axis known as the scape. There will be 50-2000 flowers per inflorescence, consisting of cymes of 5-10 flowers each. Flowers are cross-pollinated by insects; the fruit is a globular capsule and seeds are smooth and plump, 6 x 4 mm. Several cvs have been identified.

Though adapted to a wide range of conditions, onions prefer a mild climate with cool conditions and adequate moisture but not excessive rains for early growth, and warm and dry conditions towards maturity. The optimum photoperiod is 11-16 h. They are grown on a wide variety of soils; optimum pH is 6-7.

The crop is propagated by seeds (about 5kg/ha) which are either sown directly or 10-12-weeks-old, and about 20 cm-long bulbs are transplanted from a closely planted nursery. Normal spacing is about 10 cm apart in about 40 cm-wide rows. Irrigation is needed in drier climates. The crop responds well to organic manures; fertilizers are commonly applied when grown commercially. Maturity is attained in 90-150 days, when the tops drop. Harvested bulbs are cured by drying under shade for 5-10 days. Average yield is about 10t/ha; much higher yields have been reported.

The crop needs some care, including manuring and irrigation, for optimum results. However, it can be grown for supplementary income in the backyard along with other species, and also under light canopies of trees.

WINGED BEAN (GOA BEAN) *Psophocarpus tetragonolobus* (L.) DC
(Leguminosae - Papilionoideae)

This legume, which is also known as aspargus pea, four-angled bean and Manila bean, is grown mainly for its tender pods which are sliced and cooked like green beans, but the ripe seeds are also eaten; young leaves, shoots and flowers are used as a vegetable and the tuberous roots are also cooked and eaten. It is also fodder and green manure cover crop.

The nutritive value of the ripe seeds is very close to that of soyabean, with high contents of vitamin A and lysine.

FOOD CROPS

The plant is believed to be a native of Asia, or of Africa from where it spread to Asia. It is now grown mainly in South and Southeast Asia (extensively in Melanesia), and to some extent in West Africa.

It is a climbing perennial, usually grown as an annual. It grows to about 3 m height when supported. Roots are numerous and heavily nodulated; they arise from main laterals running horizontally near the soil surface and become thick about 2 months after planting. Leaves are trifoliate with long petioles; flowers are borne on axillary racemes bearing 2-10 blue or whitish flowers; pollination is mainly by bees, in the absence of which pod set may be low; pods are four-sided with characteristic serrated wings, each containing 5-20 seeds up to 1 cm long and white, yellow or brown in colour.

The plant is grown between 10^{o}S and 20^{o}N latitudes, in elevations up to 2000 m. It thrives best in hot wet climates with an annual rainfall of 1500-2000 mm; short days are preferred for normal flower induction. The crop is adapted to a wide range of soils provided they are well drained; it does not tolerate salinity and waterlogging.

Winged bean is propagated by seeds, and is often grown mixed with other annuals, and sometimes in pure stands. Trellises or wire fences are provided to support the plant. Usual spacing is 60 x 60 cm with 3 seeds per hole. Spacing varies considerably in different countries; closer spacing is adopted for root production. First green pods are ready for picking 8-10 weeks after planting, and production continues for several weeks. Tubers can be harvested 7-8 months after sowing. Yield varies considerably: seed yields from 1000-2500 t/ha and equal quantities of tuber yields are common.

Winged bean is a crop of very high potential for small-scale production and it seems to be very suitable for agroforestry in the humid tropics, where it can be grown under trees, and the trees can be used as supports or as trellis poles.

FRUITS AND NUTS

BRAZIL NUT *Bertholletia excelsa* Humb. & Bonpl. *(Lecythidaceae)*

Brazil nut, one of the important commercial nuts, is the seed of this tall large tree that grows to about 40 m height, mostly in a wild state in the Amazon forests. The kernel contains 70% oil, and it is also used as a food by the local Indians in the Amazon basin. Nearly all the world's supply of Brazil nuts of over 50,000 t/year is obtained from Brazil, mainly from Para State (Brazil nuts are therefore also called Para nuts); attempts to introduce the tree to Malaysia, the West Indies and elsewhere have not been successful.

The tree has a straight trunk, which gives excellent timber; leaves are alternate, short-stalked and large (25-50 x 10-15 cm); flowers are pale yellow, about 5 cm in diameter, borne in upright panicles; fruit is woody, globose, brown, 12-15 cm in diameter with a very hard, thick outer shell. There are about 12-24 seeds in a fruit; seeds are triangular in transverse section, and the edible portion consists almost entirely of the swollen hypocotyl.

The trees begin fruiting when they are 10-15 years old; the fruits take about one year to ripen. The fruits fall off naturally and are collected and then opened with a machete or small axe to separate the seeds.

Since the tree grows very tall, it can be used in spite of its relatively dense canopy as an overstorey species in agroforestry.

CUSTARD APPLE (SWEETSOP OR SUGAR APPLE)
Annona squamosa L. *(Annonaceae)*

Custard apple is the most popular among the annonaceous fruits. Another species, *A. reticulata*, known as "bullock's heart", is also sometimes referred to as custard apple. The edible portion is the custard-like, granular pulp in which the seeds are embedded. The pulp contains 16-18% sugars and it has a characteristic sweet, slightly acid taste; it is commonly used as a dessert fruit.

The plant is a native of the West Indies and South America and is now widely grown throughout the tropics at low and medium altitudes, especially in Southeast Asia. It is a woody shrub or small tree with a fairly stout trunk that reaches a height of 5-6 m. The branches have alternate, lanceolate and acuminate leaves. The flowers are greenish-yellow in colour and are borne singly or in small groups in extra-axillary position. The fruit is yellowish-green, heart-shaped, 7-10 cm in diameter and covered with rounded fleshy tubercules representing loosely adhering carpels that separate readily when the fruit is ripe. The fruit has a whitish or bluish bloom when it is ripe.

The fruit is very perishable and is therefore not very popular outside the area where it is grown. Fruit set, which under natural circumstances is low, can be enhanced by hand pollination.

Similar to other annonaceous fruits, custard apple also has not received much research or commercial attention so that it has not gained much popularity. It is usually a crop of the backyard where it grows in admixture with other fruit trees and shrubs and herbaceous species. Under such circumstances, it can be advantageously used as an agroforestry species.

DURIAN *Durio zibethinus* Murr. *(Bombacaceae)*

Durian is a famous, but somewhat controversial fruit of the Far East. It is grown mainly in Malaysia, but is also popular in Indonesia, southern Thailand and the Philippines. Attempts to grow it in other places of similar climatic conditions have not so far been successful.

Durian is a medium-sized or large tree growing up to 30 m height. Leaves are oblong and acuminate; flowers are cauliflorous, large, and white or pink. Fruits take about 3 months to develop. The fruit is a large ovoid-to-spherical capsule that grows as large as 30 cm long and 15 cm in diameter. It has a hard, thick, sharp-prickled skin. The fruit does not mature until it falls from the tree. The interior of the fruit is divided into five cells, each containing up to four seeds enveloped in a firm, cream-coloured, edible pulp, which must be eaten within a short time as it becomes rancid and sour quickly.

The fruit has a strong, disagreeable odour that has been described as an abominable stench of over-ripe cheese, rotten onion, turpentine and bad drains. People in Malaysia and the Far East are very partial to the fruit, but others find it difficult to overcome the odour. Wild animals, particularly elephants, tigers and monkeys, are very much attracted by its odour.

Durian is grown in humid lowlands up to 800 m elevation. Propagation is by seeds, but improved types can easily be reproduced by budding. Fruiting commences about 7 years after planting. The seeds lose their viability very quickly. There are a few other species of *Durio*, but they are virtually unknown.

Durian trees provide important revenue for villagers and farmers, even with very little care. They are usually grown mixed with other species. Thus, in Southeast Asia, Durian can be used advantageously as an agroforestry species.

GUAVA *Psidium guajava* L. *(Myrtaceae)*

Guava is a very popular fruit of the tropics; the fruits vary in size and flavour, ranging from sweet to tart. They are either eaten raw or after removal of the seeds they are canned, and made into jam, jelly, paste, juice and nectar. Guava is rich in vitamin C. It is a native of tropical America, but today it is widely distributed all over the tropics; in some places (for example, Fiji) it has even been declared a weed.

The plant is a shallow-rooted large shrub or small spreading tree, 3-10 m in height. The main trunk branches near the base with several more-or-less erect branches, each with laterals. However, in cultivation, the trees are pruned to a more regular shape. Leaves are opposite and glandular, 5-15 x 3-7 cm. Flowers are axillary, 2.5-3 cm in diameter, solitary or in 2-3-flowered cymes, white in colour. The fruit is a globular, pear-shaped berry 5-10 cm in diameter; the calyx lobes persist at the tip; the exocarp is pale green to bright yellow; the fleshy mesocarp is of varying thickness and colour, and numerous 3-5 mm long seeds are embedded in the flesh. There is considerable variation in the size, shape, colour of flesh and flavour of fruits.

Guava grows in the tropics from sea level to about 1500 m elevation in a wide range of conditions. It can withstand occasional waterlogging, high temperatures and drought, but not frost.

The most common method of propagation is by seeds that are first sown in a nursery. Vegetative propagation is also practised by budding and grafting, in which case the watershoots and suckers from the rootstocks will have to be removed. Suckers, the production of which can be induced by severing the roots about 1 m from the trunk, also can be used for propagation. The usual spacing in the field is 5-6 m. Pruning to shape the trees and removal of watershoots and suckers are carried out regularly. The tree responds well to manuring, especially to nitrogen.

Fruiting commences two years after transplanting; full bearing is attained in about 8 years, and continues for 30 years or more. The fruits mature five months after flowering and are picked up before they are fully ripe to facilitate transporting to distant markets. Average yield is about 500 fruits, i.e., about 100 kg per tree per annum; layered trees yield up to 2000 fruits per annum.

Guava can be interplanted with other species and as an understorey species with tall trees.

MANGOSTEEN *Garcinia mangostana* L. *(Guttiferae)*

Mangosteen is a delicious tropical fruit cultivated in Malaysia and other parts of Southeast Asia. Attempts to introduce it to other tropical countries have not so far been successful. But there are species of *Garcinia* that are indigenous to Africa and parts of India, the fruits of which are not as tasty. Some of them yield the dye gamboge from the latex.

Mangosteen is a slow-growing, glabrous, evergreen tree, growing up to about 12 m in height. It has a compact conical shape with numerous simple, dark, shiny green leaves, 15-25 x 6-10 cm in size. Flowers are male or hermaphrodite; male flowers are carried in groups of 3 to 9 in terminal fascicles; hermaphrodite flowers are larger, 5-6 cm in diameter, and are borne singly or in pairs, at the end of the branchlets. Fruit is a globose berry, usually parthenocarpic, flattened at the base, with persistent fleshy calyx lobes at the base and stigma lobes at the tip. The pericarp is purple, rough, and thick; the soft part of the berry consists of 4-8 translucent white fleshy segments similar to the segments of the mandarin orange. Seeds are 0-3, about 2 cm long.

Mangosteen requires a hot, humid climate with a well-distributed rainfall, a well-drained soil and shade in the early stages of growth. The plant is difficult to establish since the seeds have a short viability and low germination percentage and vegetative propagation is seldom successful. The seedlings are very slow-growing; they are transplanted when two years old with a large ball of earth to accommodate the long tap root. Trees begin to flower 10-15 years after planting. Fruits mature in about 5 months, and are harvested when they are ripe. The average yield is 300-600 fruits per adult tree per annum. The fruits are eaten fresh.

Mangosteen is a preferred species for orchard farming and other forms of mixed culture in Southeast Asia. However the plant's tendency to bear only in alternate years, the long gestation period of up to 15 years, and the difficulty in propagating it vegetatively are disadvantages.

PEJIBAYE (PUPUNHA) *Guilielma gasipaes* (H.B.K.) Bailey *Palmae*

Pejibaye or peach palm has been grown in tropical America since ancient times, and sizeable stands exist all over the region. The economic produce is the fruit which is 2-6 cm long, borne in bunches weighing up to 12.5 kg and consisting of up to 300 fruits. The fruit has a starchy mesocarp surrounding a seed. It tastes similar to the chestnut, and has a high content of carbohydrates, protein, oil, minerals and vitamins. The seed kernel is also sometimes eaten.

The plant is a monoecious feathery palm. The stem is slender, up to 15 m tall, spiny and emerges from a common root stock.

Fruit bunches mature in about 6 months and they remain on the palm in good condition for long periods; 5-6 bunches are produced on each stem per season; two crops are usually harvested per year.

The plant is adapted to tropical conditions, up to 1200 m elevation, with annual rainfall of about 2000 mm. It is propagated by seeds, although suckers are also formed. Seed-propagated plants bear in 6-8 years and last for up to 70 years. Pejibaye grows best on heavier soils like clay and clay loam.

The fruits are boiled in salt water for about three hours, the outer skin peeled off, the seeds removed and then eaten.

Pejibaye palm is widely adaptable, its fruit is very nutritious, and it is grown mixed with several other tree species; grasses for cattle grazing are also grown under mature palms.

Centro Agronomico Tropical de Investigacion y Ensenanza, Turrialba, Costa Rica, is conducting research on Pejibaye.

RAMBUTAN *Nephelium lappaceum* L. *(Sapindaceae)*

Rambutan is a delicious fruit of the East, and the plant is a native of Malaysia. It is seldom grown outside its native area, but is very popular in Malaysia and other parts of Southeast Asia.

The plant is an evergreen, bushy, dioecious tree growing up to 20 m height. Leaves are pinnate with 2-4 pairs of elliptical leaflets that are 5-20 x 3-10 cm. Flowers are in axillary panicles, and are about 4 mm in diameter. Fruits occur in pendent clusters, greyish red or occasionally yellow, globose and 3-5 cm in diameter, covered with soft, 1-1.5-cm-long spines. The seed is covered with whitish, sweet, juicy, plum aril, which is the edible portion.

The tree grows in the lowland humid tropics of Malaysia. It is usually propagated by seeds, but vegetative propagation by mar-cotts and budding is also possible. Seedling trees fruit in 5-6 years. The adult tree yields 200-400 fruits per annum. The fruits are eaten fresh.

Rambutan also can be mixed with other trees, shrubs and herbaceous plants, especially in orchard farming and homestead gardens in Southeast Asia.

SAPOTA, SAPODILLA, CHIKU *Manilkara achras* (Mill.) Fosberg
syn. *M. zapotilla* (Jacq.) Gilly
Achras zapota L. *(Sapotaceae)*

The ripe fruits of sapota (or sapodilla) are a much-preferred dessert fruit, and the latex from the stem, which contains 20-40% gum, is a raw material (chicle) for the manufacture of chewing gum. The wood is very durable and is a good construction timber.

The tree is a native of Mexico and Central America, and is now cultivated throughout the tropics, the major producing regions being Southeast Asia and South and Central America.

Sapota is an evergreen forest tree growing about 20 m tall. Leaves are elliptic-to-obovate, 5-15 x 3-6 cm in size; flowers are solitary and are produced in leaf axils; fruit is a greyish brown globose or ovoid berry, 5-10 cm in diameter, and it contains about 14% sugar, chiefly sucrose.

Sapota is usually propagated by seeds, but vegetative propagation (budding and grafting) is also possible. Fruiting starts 3-4 years after planting; fruits mature in about 4 months; mature trees yield 2500-4000 fruits per annum. Latex is obtained by tapping the trunk every 2-3 years.

Sapota can be grown mixed with other trees and annuals and can be used as a good species for providing supplementary income.

SOURSOP *Annona muricata* L. *(Annonaceae)*

Soursop, which is known as guanábana in Spanish and graviola in Brazil, is one of the several Annonaceous species native to tropical America that yield edible fruits. The fruits are mainly eaten fresh, but can also be processed and preserved without losing their aromatic flavour. Soursop also offers export possibilities as a processed industrial commodity.

The plant is adapted to the lowland areas in the tropics up to about 1000 m altitude; it is cultivated mainly from Central America to the coastal valleys of Peru, but is spread throughout the lowland tropics. It is a small evergreen, low-branching, bushy-looking tree, growing to a height of up to 10 m.

The tree is adapted to a wide range of soil conditions, but will not tolerate waterlogging. It is the least hardy of the annonas. It is usually grown from seed, but can be easily propagated by budding onto rootstocks of the same species. Plants start flowering in the third year, but fruit setting is often poor because the flowers are protogynous and the stigma loses its viability before it is shed. Fruit setting can be enhanced by hand pollination.

The tree is not a prolific bearer in normal situations, the average yield being 12-24 fruits per tree. Fruits vary in size and form and often weigh 4 kg or more. The white, fibrous, juicy flesh smells somewhat like pineapple, but with a unique musky, somewhat acid flavour. The fruits have very low keeping quality.

Soursop is seldom grown extensively on a commercial scale, but it is a common species of the backyard where it grows well in combination with other species. Therefore it can be grown between or under tall-growing trees, and mixed with herbaceous species.

SPICES AND CONDIMENTS

ALLSPICE *Pimenta dioica* (L.) Merril
syn. *P. officinalis*
(Myrtaceae)

Allspice or pimento, also known as Jamaica pepper is the dried unripe berries of *Pimenta dioica*. It combines the flavours of cinnamon, clove and nutmeg (and hence the name), and is a preferred culinary spice of commerce. The ripe berries are used in Jamaica for flavouring a special drink based on rum and known as pimento dram.

The plant is a small evergreen tree, up to 9 m in height, native to the West Indies and Central America. It is closely related to the clove tree, with a slender erect main trunk branched profusely in its upper part. The trunk has a smooth grey bark that sheds twice a year. Inflorescences are terminal, many-flowered cymes and flowers are functionally dioecious although structurally hermaphrodite. Insects and possibly wind aid in pollination. The fruit is a sub-globose berry, usually two-seeded.

The tree in its natural habitat grows in a hot, fairly dry climate, with rainfall exceeding 1500 mm per annum, up to about 300 m altitude. It requires good drainage. Outside Jamaica, it is also grown in South and Central America. In Jamaica the trees are usually self-sown or they regenerate naturally. In commercial cultivation, they are sown from seed or sometimes propagated vegetatively by cutting, budding and approach grafting. Seedlings for berry production are planted at 7-8 m spacing, while those for leaf production (for the leaf oil) are planted much closer. Very little care is usually given. In fertile soils, the trees come into bearing in 5-6 years, attaining full bearing in another 10-15 years, and lasting for the next few decades. Berries and leaves are usually not harvested from the same tree. The berries mature in 3-4 months after flowering and are collected before they are fully ripe, when still green; the inflorescence branches are broken off and the fruits then picked from the twigs. The berries are dried in the sun for 7-10 days with occasional rakings. Dried berries give a rattling sound when shaken in the hand. Recovery of dried berries from the green berries is about 60%. Average yield is about 5 kg green berries per tree per year, but yields as high as 60 kg/tree have also been reported.

Allspice is usually grown mixed with other crops including trees. In commercial plantings, cattle grazing under the trees is a common practice. Young trees are also intercropped with banana, maize, etc.

FENUGREEK *Trigonella foenum-graecum* L. *(Leguminosae - Papilionoideae)*

Fenugreek is a native of southern Europe and Asia that has been in cultivation in India and parts of North Africa for several centuries. The seeds are used as a spice and a flavouring material. Though grown mainly for local consumption in the growing regions, they are also exported from India and Morocco. The plant is a softly hairy annual plant with erect fairly stiff stem which branches at the base, and attains a height of up to 30 cm. It has a long tap root and a mass of nodulating fine laterals. The leaves are alternate and trifoliate. The flowers are white, axillary, and are carried singly or in pairs. The fruit is a narrow long indehiscent pod containing numerous small, oblong, greenish-brown seeds.

The plant is propagated by seeds and the crop attains maturity in 3-4 months. Yield varies from 1000-2500 kg/ha in India. Seeds are highly aromatic and contain an essential oil.

The plant is not adapted to lowland tropics and even in the areas where it is grown, it is not a major crop. However it can be grown under agroforestry-like conditions, though to a limited extent.

NUTMEG *Myristica fragrans* Houtt. *(Myristicaceae)*

Two important spices are obtained from the fruits of this tree: nutmeg, the dried seed, and mace, the dried aril. They are also used for medicinal purposes, in sauces and ketchups, and as flavouring agents.

Nutmeg is a native of the eastern island of Moluccas. It is now cultivated mainly in Indonesia, other parts of Southeast Asia, and to some extent in the southern part of India and in the West Indies.

The plant is an evergreen, spreading, dioecious tree attaining a height of about 10 m in cultivation. The root system is superficial; the main trunk is thick and it produces spreading branches. Foliage is thick and somewhat luxuriant; leaves are alternate, ovate, simple and pointed, dark green and borne on short petioles. Flowers are unisexual and male and female flowers are produced on separate trees, but very rarely hermaphrodite trees are also found. Sex differentiation is difficult before the trees flower. Flowers are borne singly or in cymose clusters; male and female flowers are similar; they are bell-shaped, fragrant, pale yellow, and nectiferous at the base; male flowers are 5-7 mm long and female flowers slightly larger. The fruit is a fleshy drupe, yellow, smooth, 6-9 cm long and with a circumferencial longitudinal ridge and persistent remains of the stamina. Pollination is by insects or wind.

Nutmeg requires a hot humid climate, with no pronounced dry season. The soil should be rich in organic matter and well drained. The tree prefers partial shade: sheltered valleys are the best-suited.

Nutmeg is normally propagated by seed; germination takes 4-6 weeks. Seedlings are transplanted when they are about 6 months old and 15 cm high. To overcome the difficulty of delayed (after 6-8 years) sex-differentiation, vegetative propagation (inarching and approach-grafting) is practised, though it is not yet very popular.

Usual field spacing is about 7 m. Trees start bearing in 6-8 years, attain full bearing in 15-20 years, and continue for 30-40 years more. Fruits ripen 5-6 months after flowering. A tree produces 1500-2000 fruits per year. The aril attached to the tip of the seed is carefully detached, flattened by pressure between boards, and dried to obtain the mace of commerce. Yields vary from 500-1200 kg nutmeg and 100-250 kg mace per ha per annum.

Nutmeg prefers partial shade and in Moluccas it is grown under big trees. In spite of its spreading canopy, crops such as banana, yams etc. are interplanted with nutmeg.

UMBELLIFEROUS SPICES

Several herbaceous plants belonging to the family *Umbelliferae* are cultivated in the tropics, mainly for their flavoured fruits which are used as spices, flavourings etc. The plants are mostly short-duration annuals and they do not grow well in the lowland humid tropics. Usually they have thick, erect, hollow stems, large alternate leaves, and an inflorescence that is characteristic of the family, in the form of a simple or compound umbel. A simple umbel has a number of peduncles, each with a single flower and subtended by a tract. These plants are of some potential in agroforestry in a limited scale in the areas that are suitable for the crops. They are of short duration; they need little care and they can be grown under light shade.

The species that are found throughout the tropics, especially in North Africa and India, and that could be of some potential in agroforestry are anise, coriander, cumin, dill (which is rarely grown in the tropics) and fennel.

ANISE (ANISEED) *Pimpinella anisum* L.

This plant is native to the eastern part of the Mediterranean region and has been in cultivation for a very long time there and in India and Mexico. It does not grow satisfactorily in tropical lowlands. It is an annual, attaining a height of 60-90 cm. The small white or yellow flowers produce small fruits that split into two mericarps, each 3-5 m long and 2 mm wide. They are used to flavour curries and other culinary preparations as well as liqueurs. They also yield an essential oil on distillation, which is used in medicine, perfumes, etc. The leaves are also used for seasoning, cooking, etc.

SPICES AND CONDIMENTS

CORIANDER *Coriandrum sativum* L.

Coriander is native to the area from the eastern Mediterranean to the Middle East and is now extensively cultivated in India, the Middle East and some parts of Brazil, but is not suited to tropical lowlands. Its main trade in the East is as a constituent of curry powder and for use in pickling and seasoning; it is also used in medicine and veterinary medicine. Coriander is the hardiest and most widespread of the umbrelliferous spices. It is an annual herb with a slender smooth sheathing base bearing leaves, and is 40-70 cm high. Fruits are globular, about 3 mm in diameter, 2-seeded, and pleasantly aromatic when fully ripe. In India, the usual seed rate is 10-20 kg/ha; it matures in 3-3½ months and yields 1000-2000 kg dried fruits per ha.

CUMIN *Cuminun cyminum* L.

Cumin is another umbelliferous spice that is native to the Mediterranean region, has been in cultivation for a long time, and is now extensively cultivated in India, Iran, Sudan, Egypt and the Mediterranean islands. However, it is not adapted to tropical lowlands. It is an essential ingredient of curry powder and is used as a flavouring agent. The essential oil is used in perfumery and for flavouring beverages. The plant is a slender much-branched annual herb, up to about 30 cm height with fruits about 8 mm-long, greyish and narrow. The plant can be harvested 60-90 days after sowing.

FENNEL *Foeniculum vulgare* Mill.

Fennel is also a native of the Mediterranean region that has been in cultivation as a cold weather crop since early times in India, China and Egypt, and is used in curry powder and as a flavouring agent. All parts of the plant are aromatic and the leaves are used as a pot herb. The oil is also used as flavouring agent as well as for cooking. The plant is a stout, erect, glaucous perennial with much-divided leaves, small, yellow flowers, and ovoid, 5-6 mm long and prominently-ridged seeds. The volatile oil content varies from 1-6%.

BEVERAGES AND STIMULANTS

BETEL VINE *Piper betle* L. *(Piperaceae)*

The leaf of betel vine (also known as betel pepper) is an essential ingredient of the betel quid or "pan", the other important ingredient being arecanut or betel nut *(Areca catechu* L.); the habit of chewing the quid to stimulate saliva production is very old among the people of India, Southeast Asia and East Africa.

The plant is an evergreen perennial woody climber resembling black pepper, and is a native of Malaysia. It is cultivated in Asia and East Africa where "pan" chewing is popular. The stem is noded with dimorphic branching consisting of orthotropic vegetative branches with adventitious roots that adhere to the support, and plagiotropic axillary fruiting branches without roots. Leaves are dark green with 5-9 veins, a broad base and an acuminate tip. Several cvs have been recognized in India and elsewhere.

The plant is cultivated from sea level to about 900 m elevation in the tropics, in areas with good rainfall and fertile soil. It is usually grown under shade in homestead gardens with intensive care in manuring and irrigation. Propagation is by 30-45 cm-long cuttings with 3-5 nodes taken from the tips of orthotropic vegetative shoots. Areca palms or specially planted quick-growing trees such as *Sesbania grandiflora* and *Erythrina indica* are used as the supports. Close planting and heavy manuring are practised to promote leaf production.

Harvesting (plucking of leaves) begins in the second year; usually leaves from the plagiotropic axillary branches are plucked four times a year on a rotational basis. The upper branches produce the best quality leaves for chewing; therefore, the vines are annually lowered and coiled around the base of the support. Thus the vines are not allowed to grow more than 3-3.5 m high, which also facilitates harvesting. Since the economic produce is the fresh green leaves, harvesting is adjusted to meet the market demands. Yield varies considerably from 2-30 million leaves per hectare annually. Economic life-span of good plantations is about 20 years.

The cultivation of betel vine is an "intensive" agroforestry practice, involving high labour requirement. However, most commercial plantations are less than 0.5 ha in area.

BRAZILIAN CACAO (CUPUACU) *Theobroma grandiflorum* (Wild et Spreng.) Schum *(Sterculiaceae)*

This plant is very similar to the more prominent species of the genus, *Theobroma cacao*, with respect to its growth habits and requirements. The pulp around the seeds is used for making a drink in parts of Brazil, and is also used as a flavouring agent. It is grown as an understorey species in cleared forests in the lowland humid tropics where cacao grows. The fruits are 2-3 times bigger than those of cacao, but the number of fruits per tree is less. No research seems to have been done on the species, nor any effort made to exploit its potential.

COLA NUT *Cola* spp. *(Sterculiaceae)*

Several evergreen medium-sized tropical trees belonging to the genus *Cola* are found in West Africa; they produce fruits containing seeds that are erroneously called nuts, and are used as stimulants in beverages and as masticatories. The best known species is *Cola nitida* (Vent) Schott et Endl., also known as Gbanja kola. It is a native of the forest zones of Sierra Leone, Ivory Coast and Ghana, and it is now planted all over West Africa and also in the West Indies, Brazil and India.

Cola nitida is a 10-15 m high tree; the trunk is unbranched in its lower part; leaves are large and flat with prominent lateral veins; inflorescence is axillary; flowers hermaphrodite or male; usually self-pollinated; fruit is borne on short hanging peduncle, up to 12 x 7 cm and containing 4-10 seeds per carpel in 2 rows. There are two cotyledons and they are white, pink, or red. The fruits mature in 4-5 months.

Cola nut favours warm tropical climates with 140-170 cm of annual rainfall; its natural habitat has pronounced wet and dry seasons. It grows best on light, well-drained soils that are fertile and rich in humus. However, soils that are not good for cacao are used for cola. Sometimes cacao and cola are interplanted, when cola provides the shade for cacao.

Propagation is by seeds and germination occurs in 7-12 weeks. Usually the seeds are planted at stake at 6-8 m distance. Growth is in flushes. During the early years of growth, food crops are usually interplanted. Fruiting commences in about 7 years and full production is attained in 10-12 years. Trees continue bearing until about 80 years old. The main harvest in West Africa is from September to January; fruits are harvested by cutting with a curved knife tied to the tip of a long pole. The follicles are then split and the seeds fermented in heaps for 5 days, and then they are washed and cleaned. The average yield is about 250 kg nuts per tree per year; much higher yields are also reported.

The seeds contain about 2% caffeine, a trace of theobromine, a glucoside called collanin and an essential oil.

Cola nut is usually grown under agroforestry-like conditions.

GUARANA *Paullinia cupana (Sapindaceae)*

The seeds of guarana contain 4-6% caffeine; a beverage is prepared from the seeds and it is about three times stronger than coffee. The drink prepared from guarana is very popular in Brazil, especially in the Mato Grosso region, where it is also cultivated. It has some medicinal properties.

Guarana is a perennial woody vine native to the Amazon basin; the cultivated form is a small shrub. There are two varieties, var. *typica* and *sorbilis*. The varieties differ in the structure (compact or loose) and colour (red or yellow) of the inflorescence. The seeds are covered by a thick husk.

It is usually cultivated as an understorey species with trees, in poor latosols, but having a layer of organic matter on the surface. It prefers warm humid climates with well-distributed rainfall. Propagation is by seeds, which have very short viability (about 3 days) after they are harvested. Therefore the seeds have to be sown quickly. It can also be propagated by stem cuttings. Seeds are usually sown in nursery beds, after removing the husk and the seed coat. Germination is very slow, and the seedlings emerge in about 3 months. They are transplanted after about one year, at the commencement of rains at 5 x 5 m spacing. Young plants are trailed on to the supports and trellises. Pruning is a routine operation to stimulate production of fruiting branches. Flowering usually starts in July and the fruits mature in November. Mature fruits are harvested by cutting the whole bunch (inflorescence); they are left to ferment for a few days, after which the seeds are taken out and washed. The seeds are roasted at a low temperature and the seed-coats removed. Seeds are stored or sold as such, or they are ground, and moistened to form a paste which is then moulded to cakes and smoked. These harden on keeping, and can be kept in cake form for long periods without deterioration. Guarana is usually grown under trees and is a good species for agroforestry.

Instituto de Pesquisas e Experimentacao Agropecuarias do Norte (IPEAN), Belém and INPA, Manaus are the Brazilian National Institutes that carry out studies on Guarana.

MATÉ (PARAGUAYA TEA) *Ilex paraguayensis (Aquifoliaceae)*

Maté or Paraguaya tea is the most popular stimulant beverage of South America. Numerous species of *Ilex* produce caffeine-containing leaves, and the wild plants occur in southern Brazil, Paraguay, Uruguay and Argentina. The dried leaves contain over 1% caffeine. The drink prepared from the dried and ground leaves is a stimulant believed to have medicinal properties.

Maté is a shrub or small tree growing to about 6 m height in the natural state but in cultivation it is a shorter, many-stemmed bush due to pruning. The main branches are fairly stout and there are several finer, highly branched laterals. Leaves are alternate, simple and ovate, 10-12 cm long with serrated margins and acuminate tip. Inflorescences are axillary cymes, consisting of small whitish flowers. The fruit is a reddish drupe, that has very short viability.

The plant is usually cultivated in the mountainous areas in poor soils. Propagation is by seed, but the seeds should be sown immediately because of their short viability. The leaves are collected from the plants every two or three years: the young shoots are cut and passed over a fire to dry the leaves thoroughly; the dried leaves are beaten with sticks and broken to about 5-cm-long pieces; they are then dried in special ovens and finally crushed ready for use. Sugar and lemon are usually added to maté and it is usually drunk from cups with a narrow opening, by means of long tube with a sieve at the distal end; the tube is called a "bombilla".

Very little maté is exported from South America, and the plant has not been introduced into other tropical countries. However, in South America it is a good species for agroforestry because of its adaptability to poor soils in mountainous areas.

VANILLA *Vanilla planifolia* Andrews
syn. *V. fragrans* (Salisb.) Ames *(Orchidaceae)*

Vanilla, the important and popular flavouring agent, is obtained by fermenting the fully grown, but not fully ripe, fruits of this orchid, usually referred to as vanilla beans. It is extensively used in ice-cream and confectionary. The plant is a native of Mexico and Central America; today the major producers are Madagascar (which accounts for 90% of the world crop), Mauritius, the Seychelles, Southeast Asia and Brazil.

Vanilla is a succulent climbing perennial vine; stems are brittle, 1-2 cm in diameter, and reach a height of 10-15 m on trees or other supports; but in cultivation the stems are trained and kept shorter. Internodes are 5-15 cm long; each node produces fairly fleshy, thick, oblong and sharply pointed alternate leaves and whitish, thin aereal adventitious roots. Inflorescence is a short axillary raceme with up to 25 large waxy, fragrant, greenish-yellow flowers. The fruit, commonly known as the bean, is a capsule, triangular in shape, 15-20 cm long, and 0.8-1.0 cm in diameter; when ripe it splits into two halves. Seeds are minute, black and numerous.

Natural self-pollination is impossible because the stamen and stigma are separated by a rostellum. In Mexico, cross-pollination occurs (by bees); in all other places, hand-aided self-pollination is carried out.

Vanilla requires some sort of support to climb up, light shade, and a humus-rich soil. In commercial plantings propagation is by 90-100 cm-long cuttings. Sometimes quick-growing support trees are planted before planting vanilla; it is also grown up posts or trellises; in both cases, light shade should be provided. Mulching, organic manuring, and regulating of shade are important. Plants flower about four years after planting; sometimes the tip of the growing branch is pinched to induce flowering. Various hormones are also administered for the same purpose. The flowering season lasts about 2 months. Hand-pollination is usually done by women and children; an individual can handle 1000-2000 pollinations per day.

Fruits mature in 7-9 months. Beans are harvested before they are fully ripe and they are cured by a process of alternate sweating and drying; by which the characteristic aroma develops. About 6 kg green beans yield 1 kg cured beans; an average of 500 kg cured beans is obtained during a crop's life of about 7 years.

Vanilla cultivation is a system of agroforestry because it is usually grown on trees. Hand-pollination, which is a must, can be done by women and children.

MEDICINAL AND AROMATIC PLANTS

BASIL *Ocimum basilicum* L.
syn. *O. americanum* L. *(Labiatae)*

The dried leaves and flowering shoots of *Ocimum basilicum*, known as basil or sweet basil, and of another species *O. canum*, are used as a spice for soups, sauces, and other foods, and as a pot herb. Basil is native to the Old World tropics and is now distributed all over the tropics, sometimes as a weed in cultivated fields. It is a slightly hairy annual with highly branched angular stems with opposite leaves that are ovate and about 5 cm long. Flowers are small, white and carried in open racemes in leaf axils or terminally. Usually they are cross-fertilized.

There are several species and forms and cross-fertilization occurs between types. The quality of oil varies considerably, depending upon their growing conditions and forms. Basil oil is commercially valuable as it is used for scenting soaps, in the perfume industry and for flavouring liqueurs. It is a hardy species with wide adaptability and therefore will be of value in agroforestry, though only to a limited extent.

BAY TREE *Pimenta racemosa* (Mill.) J.W. Moore
syn. *P. acris* Kostel. *(Myrtaceae)*

Bay oil, which is distilled from the leaves of the bay tree, is used in perfumes and in the preparation of toilet articles and bay rum. The tree is very similar to allspice, *Pimenta dioica*, and is grown in the West Indies and parts of Central America. It has also been introduced to other parts of the tropics, particularly East Africa and Sri Lanka.

It is a small, erect tree reaching a height of about 7 m with dark green, shiny, elliptical, leathery leaves up to 10 cm in length and short petioles. The flowers are small and white on much-branched cymes or corymbs, similar to those of allspice. Fruits are small and they turn black when ripe.

The bay tree is cultivated mainly in the West Indies, from where the leaves are exported to distilleries in the U.S.A. In cultivation the tree is kept to a height of less than 2 m by pruning to facilitate leaf collection.

Though not commercially a very important species, the bay tree can be a good species for agroforestry in its natural habitat, since it grows in combination with other trees and shrubs, is easy to manage, and gives economic returns.

CALAMUS (SWEET FLAG) *Acorus calamus* L. *(Araceae)*

The rhizome of this plant contains 1-3% yellow oil which is similar to patchouli oil in odour. The aromatic rhizome known as calamus root contains a glucoside, ascorin, used in Oriental medicine; the oil is used in perfumes and the candied rhizome is a popular confection.

The plant grows wild in marshy places and banks of streams in southern Asia, especially India and Sri Lanka, where it is also cultivated. It is a hardy semi-aquatic perennial herb with a creeping rhizome and erect sword-shaped leaves reaching to 90 cm in length. The rhizome is much-branched, about 2.5 cm in diameter, and consists of spongy tissue in which the oil glands are formed. The inflorescence is similar to that of taro *(Colocasia* spp.) except that it is not subtended by a spathe.

The rhizomes from the wild or cultivated plants are collected, dried in the sun, powdered and steam-distilled. Sometimes the powdered rhizome is also used in toilet powders, sachets, etc.

The agroforestry potential of the plant is due to its hardy nature and semi-acquatic habit, which makes it an ideal species for marshy lands where other species seldom survive.

CANANGA (YLANG-YLANG) *Cananga odorata* (Lam.) Hook.f. & Thoms. *(Annonaceae)*

Cananga oil and ylang-ylang oil are distilled from the fully opened flowers of this tree. When the flowers are distilled, the first portion of the distillate is ylang-ylang oil, which is used in high-class perfumes, and the remainder is cananga oil, which is used in cheap scents and soaps.

It is an evergreen tree 3-30 m tall with drooping branches and elliptical 7-20 x 4-10 cm leaves. Flowers are very fragrant, yellow green, and they hang in clusters from older wood as well as on leafy twigs. Fruits are formed in bunches, 4-12 for each flower.

The tree occurs wild in parts of southern and Southeast Asia; it is grown in gardens in India and Malaysia, and has been introduced to other parts of the tropics.

In cultivation, the tree is pruned down to about 3 m height with the branches somewhat dragged down. The plants begin to flower when they are 1½-2 years old; they yield 4-5 kg of flowers per year when they are 4 years old and 8-10 kg when 10 years old.

The flowers are harvested for oil extraction when they attain maturity, which is indicated by the change of colour from green to yellow. Flowers are collected in the dark or early in the morning as heat dissipates the delicate perfume. Trees flower all the year round, but maximum flower production occurs between November and March. Oil is extracted by steam distillation or solvent extraction, the latter giving a better product.

Ylang-ylang can be used as an agroforestry species, because usually it is not grown in monoculture.

CITRONELLA GRASS *Cymbopogon nardus* (L.) Rendle
C. winterianus Jowett *(Gramineae)*

Citronella oil, distilled from the leaves of the grass, is used extensively in the soap industry and for production of the essential oils geraniol and citronellal. The grass grows wild or semi-wild in several parts of the tropics and is cultivated in Sri Lanka, Malaysia, Java, Fiji, Guatemala and elsewhere.

It is a tall, strong, hardy perennial grass, 0.5-1.5 m tall, with broad leaves arising from the numerous narrow stems put up from the short rhizome. The panicles are mostly large and compound and the spikelets are awnless. There are several forms; the important are the Ceylon type and Java type. The former, known as *lenabatu*, is hardier and can be grown on poorer soils. The crop is first harvested about 8 months after planting and subsequently every 3-4 months for 10-15 years. The Java type is var. *mahapengiri* or *Cymbopogon winterianus;* it produces an oil with higher percentages of citronellal (40-50%) and geraniol (30-45%). The grass occurs in large clumps and harvesting is done once every 3-4 months after the first year's growth. This plant is now widely distributed throughout the tropics, but it is less robust than the Ceylon form.

The Java-type citronella grows well from sea level up to 1000 m; it needs well-distributed rainfall and a well-drained sandy loam soil. Propagation is by root cuttings and they are planted at a spacing of 0.5-1.0 m. The crop is replanted after about 5 years.

The grass is cut above the first node and dried for a short time, and then steam-distilled.

Average yield in Java is 45-80 kg/ha of oil per year; yields of over 100 kg/ha have been reported from Guatemala.

Although citronella grass grows best in abundant sunlight, it is a good species for agroforestry in sloping lands and under light shade. The root matting of the grass offers good protection to soil against erosion.

LEMON GRASS *Cymbopogon citratus* (DC.) Stapf (West Indian Lemon Grass) *C. flexuosus* (Nees ex Steud.) Wats (Malabar Lemon Grass) *(Gramineae)*

Lemon grass oil, which is obtained by steam distillation of lemon grass leaves, contains 75-85% of aldehydes, consisting largely of citral. The oil is used extensively in the soap, pharmaceutical and perfume industries. There are two important species of lemon grass, *C. citratus* and *C. flexuosus*.

C. citratus, known as West Indian lemon grass, is a tufted perennial grass with numerous stiff stems arising from short rhizomatous root stocks. It tillers profusely; the leaf blade is narrow, linear, drooping, and about 1 m long; it seldom flowers in cultivation, and it is widely distributed throughout the tropics, especially in the West Indies, Guatemala, East Africa, Congo, and Southeast Asia. The plant is propagated by root cuttings, and planted at a spacing of 1.0 x 0.5 m. Harvesting begins when the plant is 4-8 months old and then once every 3-4 months for about 4 years. Fresh grass yields 0.2-0.4% oil, with an average yield of 50-120 kg oil/ha per annum.

C. flexuouseus, known as Malabar lemon grass, is a native of the Malabar coast of India and is cultivated in poorer soils and forest clearings, mainly in southern India. It has also been introduced to other parts of the tropics such as Honduras, Guatemala, the West Indies, Southeast Asia, etc. The plant is a tufted robust perennial grass, growing about 2 m tall and flowering profusely. Red-and white-stemmed types are available, but the oil is obtained only from the former. Propagation is by seed; the first cutting is taken in about 4 months and thereafter once every 6-8 weeks for about 6 years. The oil is distinct from West Indian lemon grass oil, and is preferred in perfume-making. Average yield is about 40 kg oil/ha/year.

Lemon grass prefers warm climates with a well-distributed rainfall and well-drained soil. Usually it is grown on poor, gravelly soils; when grown on fertile heavier soils, the oil content is reduced.

Lemon grass is also a good species for soil conservation and can be used as a good species for agroforestry in poorer soils in marginal areas. Lemon grass is a smallholder crop in India, where its production is a village industry.

OCIMUM CAMPHOR *Ocimum kilimandscharicum (Labiatae)*

Camphor is a ketone derivative of a di-cyclic terpene; it melts at higher temperatures, but at ordinary temperatures camphor exists as a transparent colourless solid. It is used in the manufacture of celluloid and cellulose compounds, and also in medicines.

An essential oil containing about 60% camphor is obtained from *Ocimum kilimandscharicum*. It is a perennial shrub growing 2-3 m high in a wide variety of soil and climatic conditions, mainly in East Africa but also in India and other parts of Asia. The plant is usually grown in the lower hills on the fringes of forest and agricultural plantations, sometimes under tree canopies. The plants are best raised from seeds in a nursery and transplanted 4-5 weeks later at 30 x 60 cm spacing. The plant gives two harvests in the first year of its growth, and three harvests in later years. Usually only the leaves are distilled (steam distillation), leaving the stem for fuel. An average yield is 2000-3000 kg dried leaves per hectare in a year, giving 25-40 kg solid camphor. However, manuring gives a higher yield.

PALMAROSA *Cymbopogon martini* (Roxb.) Wats. *(Gramineae)*

Palmarosa oil, which is distilled from the flowering tops of Palmarosa or rosha grass, is used mostly as an adulterant in other more expensive oils. It is also used in perfume-making, especially in the drier parts of India, and cultivated to a small extent in Java and Malaysia. Several varieties occur that are morphologically similar but considerably different in their habitats and also in the essential oils distilled from them. The two important varieties are var. *motia* and var. *sofia*.

Variety *motia* occurs in separated clumps on open, dry, hilly, well-drained areas with an annual rainfall of about 900 mm. The oil contains up to 95% of geraniol, and is now produced in Java, the Seychelles, Malawi and elsewhere. Variety *sofia* grows densely and abundantly at lower altitudes in areas with higher rainfall and poorer drainage. It yields the less valuable ginger grass oil.

In both varieties, the oil is distilled from the flowering tops. Green grass contains about 0.3% of oil.

Both varieties can be used in agroforestry practices in their habitats: they are adapted to marginal areas and poor soils and they can be grown under dense canopies of trees and used for soil conservation work.

MEDICINAL AND AROMATIC PLANTS

PATCHOULI *Pogostemon cablin* (Blanco) Benth. *(Labiatae)*

Patchouli oil, extracted from the dried young shoots of *P. cablin*, is widely used in the making of perfumes, in scenting soaps, and to give the characteristic odour of cashmere shawls and carpets. It is native to the Philippines, and is now grown extensively in Malaysia and Sumatra. It has also been introduced to other parts of the tropics such as the Seychelles, parts of East Africa and Brazil.

The plant is a shrub, usually 1 m tall; the stem is square-angled and highly branched; leaves are opposite and are carried on fairly long petioles. When cultivated, it rarely flowers; flowers are white with purple streaks and are carried in axillary spikes.

The plant likes a warm moist climate with an evenly distributed rainfall, and grows best on richer soils at higher elevations.

Propagation is by stem cuttings; young shoots with leaves are harvested once every 6 months and continued for 2-3 years. Oil from the young leaves is of the best quality. Harvested tender shoots and leaves are carefully dried and baled for export.

Patchouli also can be advantageously cultivated as an agroforestry species at higher elevations on richer soils.

RAUWOLFIA *Rauwolfia serpentina* Benth.

The roots of Rauwolfia have been extensively used in India and Southeast Asia since very early times as an effective remedy against high blood pressure, all sorts of pains (especially rheumatic pains), snake bites, scorpion stings, etc. The medicinal property is due to the alkaloids, 22 of which have been identified. The plant is also grown in the West Indies, Brazil, and the Pacific Islands. Rauwolfia is a perennial herb up to one metre high, growing in hilly areas and mountain slopes to about 1000 m elevation. It prefers partial shade and a well-distributed rainfall of 150-400 cm per annum; it is very sensitive to waterlogging. The plant is propagated by seeds or by cuttings of roots or stems, root cuttings being preferrable. The average yield is 2000-4000 kg air-dried roots per hectare per year after the third year. Seeds are produced throughout the year, but the main ripening season is the cold weather period. Research on Rauwolfia is carried out by the Central Institute of Medicinal and Aromatic Plants, Lucknow, India and the All India Coordinated Research Project on Medicinal and Aromatic Plants, IARI, New Delhi, India.

VETIVER *Vetiveria zizanioides* (Linn.) Nash *(Gramineae)*

The valuable aromatic oil known as khuskhus oil or vetiver oil is distilled from the roots of this grass which occurs wild in many parts of the Indian subcontinent, often on rich river-bank soils. It is also found growing in many parts of East and West Africa. The essential oil is used in perfumes and in the preparation of cosmetics. The dried stems are woven into "thatties" which when moistened cool and scent the atmosphere, and are used in hot summers. The plant is a tufted, wiry, perennial grass. It grows in large clumps from a many-branched rootstock (rhizome). The clumps are 0.5-1.C m high. It prefers warm and humid climates up to 600 m elevation, and loose, sandy soil. Root slips are used for propagation, planted at about 40 cm spacing. The optimum time for harvesting is about 2 years after planting. The harvested roots are dried in the shade, powdered or crushed, and then distilled for 24-36 hours. The average yield is 5 t dried roots/ha per year, and at an oil content of 0.7-2.5%, this produces 40-100 kg oil per ha.

MISCELLANEOUS PLANTS

BABACÛ (BABASSÛ) PALM *Orbignya martiana* Barb. - Rodr. and *Orbignya oleifera* Burret *(Palmae)*

Babaçû palm is the most important oil-producing plant, growing abundantly in Brazil. The kernel, which looks and tastes like coconut meat, contains about 70% oil, but its production has not been commercialized.

The palm grows to 20 m in height; the crown consists of 15-20 pinnate leaves 6-9 m long. Fruit bunches are up to 1 m in length, each containing 200-600 fruits; 1-4 bunches are produced per year. The fruits resemble small coconuts; they are 8-15 cm long and 5-9 cm thick, weighing 150-200 g. The mesocarp is thin, but the endocarp (shell) which comprises 50-60% of weight of the fruit, is very thick; there are 3-8 kernels, which constitute about 10% of the weight of fruits and contain 60-70% oil.

There are two major species: *O. martiana* and *O. oleifera*. There are also other less-important species. *O. martiana* grows in the wet forest areas of the Amazon basin and *O. oleifera* is adapted to the dry semi-deciduous forests of Brazil outside Amazonia. The palms grow in a somewhat wild state throughout the northern and northeastern parts of Brazil, either in sole stands or mixed with other woody species. They are abundant in river valleys and deltas that are not subject to prolonged flooding, and on a wide variety of soils.

In commercial plantations, the plants are planted at about 9 x 9 m spacing, and the cultural operations are similar to those for coconuts. The fruits ripen from July to November, and then fall to the ground; the collected fruits are dried in the sun to facilitate removal of the shell from the kernel.

The babaçû oil can be used for the same purposes as coconut oil, and its local processing for soap making is expanding in Brazil. The low recovery of oil (the oil-rich kernel constitutes only 10% by weight of the fruit), difficulties in cracking the hard, thick shell and collecting and transporting the nuts are factors that limit production. However, existing stands of babaçú can be utilized profitably for intercropping and cattle grazing, as in the case of coconut stands.

There are several publications on babaçú and some are listed in the U.S.A. National Academy of Science (1975) publication, Underexploited Tropical Plants with Promising Economic Value, pp. 89-94.

BURITI PALM *Mauritia flexuosa* L.
syn. *M. vinifera* Mart. *(Palmae)*

Buruti palm, which is the most plentiful species of palm in South America, is used for a variety of purposes by the local Indian tribes. The pulp of the fruits is edible and tasty, and contains 8-9% oil; the kernel has about 50% oil, similar to other vegetable oils; the shoots can be harvested and eaten as "palm hearts" and sago is obtained from its trunk; wines are made from the fruit; fibres extracted from the young leaves are used to make a strong twine that is used for fishing nets, mats, baskets, etc., and the trunk gives the light buriti wood used for floats and rafts.

The palm is grown over most of northern South America, in the humid tropics, and especially along streams and in fresh water swamps. Extraction of its starch is at present important in the Orinoco Delta of Venezuela. It grows mostly in damp, marginal areas at low altitudes; other aspects of its agronomic requirements are not clearly known.

Buriti grows up to 25 m; the number of leaves in the crown is less as compared to other palms; leaves are about 3 m long with long stalks and a cluster of leaflets at the tip. The fruit is green, roundish, and scaly and grows in bunches. Flowering and fruiting occur annually after maturity.

Buriti palm is seldom grown outside its native habitat and no effort has been made to improve the palm and commercialize its production. It seems to be a good species for marginal swampy areas unsuitable for agriculture, and to rehabilitate such areas.

MISCELLANEOUS PLANTS

GUAYULE *Parthenium argentatum* Gray *(Compositae)*

Guayule is a potential source of natural rubber that grows naturally in the arid regions of Mexico and the southern U.S.A. Its potential was realized during World War II when America was cut off from natural sources of rubber. Interest in guayule has increased in recent years consequent to the increase in the cost of petroleum products, which are essential for manufacturing synthetic rubber.

The plant grows in the desert regions and other marginal lands north of central Mexico and southwest U.S.A., at elevations of 1000-2000 m where the annual rainfall can be less than 250 mm and the temperature ranges between 10-49^{o}C. However, for commercial production, over 400 mm of annual rainfall is necessary. Annual rainfall over 650 mm promotes excessive vegetative growth at the expense of rubber production. A definite dry season appears to be desirable. The plant seems able to withstand occasional frost, does not tolerate poor drainage and excessive salinity, but grows on soils that are too poor for other species.

Guayule is a bushy perennial shrub up to about 60 cm high, with narrow, alternate leaves covered with a drought-protecting white wax. The flowers are carried in dense heads on long stems. The plant can survive under desert conditions for up to 40 years. The rubber is contained in thin-walled cells throughout the plant, but content is high in roots and stems. Rubber constitutes an average 10% of the total dry weight of the plant.

Commercial cultivation is from seedlings that are transplanted from a nursery. During the first year, the young plants may be smothered by weeds, but thereafter little weeding or cultivation are required.

The whole plants, including roots, are harvested. The age at harvesting depends upon the growth of the plant; it can be brought to economic harvest size in 3 years, but under dry-land farming the period is much longer. The whole plant is sliced into small pieces, the tissues are macerated and the lighter rubber is separated from vegetative residues by floatation.

Harvesting and processing have been mechanized by equipment used for other crops.

The agroforestry potential of guayule is its adaptability to extreme conditions of arid and desert regions and its potential high value.

Guayule - An Alternative Source of Natural Rubber, published by the US National Academy of Sciences (1977) gives compiled information on various aspects of guayule production and processing.

JOJOBA *Simmondsia chinensis* (Link) Schneider *(Buxaceae)*

Jojoba is a shrub that grows wild in the semi-arid region of the Sonora desert in northern Mexico and southwestern U.S.A. Its seeds contain an unusual liquid vegetable wax called jojoba oil, which can serve as a substitute for sperm whale oil in the manufacture of cosmetics, candles, etc., as well as in research establishments. The shrub is also a good browse plant for animals.

Jojoba is a perennial shrub, growing 0.6 to 2 m tall, usually with many stems branching near the ground, though sometimes unbranched. There are great variations in form, foliage, fruit and yield within its natural habitat. Jojoba is dioecious; the first fruiting is in 2-5 years and thereafter annually.

Jojoba grows best in areas with annual rainfall of 400-500 mm with at least some winter rainfall. The summer temperature of its natural habitat is as high as 45°C; the minimum temperature well below 0°C. The shrub grows up to about 1200 m elevation on a variety of soils, but preferably on well-drained coarse soils. One remarkable advantage is that it withstands fairly high levels of soil salinity.

Jojoba is propagated both vegetatively (stem cuttings and tissue culture) and by seeds, the latter being more popular. Because of the dioecious nature of the plant, planting of extra seeds or seedlings is necessary. Usually one in every 7 plants will be male, so that for an eventual plant population of 1200 per ha, about 1400 plants are initially established. Sex differentiation occurs after a few years' growth.

Harvesting is usually by hand. Because of the slow and tedious nature of this operation, most of the seeds now produced in the wild stands are lost. Average yield obtained from planted stands of jojoba is 2250 kg/ha, or roughly 1.5 kg/plant annually. Clean, dry dehulled jojoba seeds contain about 50% oil, which may be extracted either by conventional expellers, or by solvents.

Jojoba is a very good species for semi-arid and dry regions, and attempts are now being made to grow it in the natural scrub and forest stands of those areas. Therefore it is of potential value in agroforestry. However, its harvesting is a tedious operation.

Jojoba: An Assessment of Prospects, published in 1979 by the Tropical Products Institute, London is the most complete reference material.

SAGO PALM *Metroxylon sagu* Rottb. *(Palmae)*

The commercial starch pellets known as sago are obtained from several tropical plants, the most important of which is *Metroxylon sagu*, the sago palm. Sago is also produced from *Metroxylon rumphii*, the prickly sago palm. Other major sago-producing genera are *Arenga*, *Caryota*, *Corypha*, *Mauritia* and *Oredoxa*. Sago is a substitute for rice, and sometimes a staple food, in parts of Asia and other parts of the tropics. The leaves of the sago palm are an excellent thatching material.

Sago palms occur wild in Papua New Guinea, Malaysia, the Philippines and other parts of Southeast Asia as fresh-water swamp trees. The palm has a stout erect trunk growing to 10 m height, which produces a vast terminal inflorescence when the palm is 10-15 years old. Subsequently the palm dies. Several suckers are produced from the main roots of the palm, which grow up about the base of the main stem thus giving a clump-like appearance in the natural stand. The crown consists of large, paripinnate leaves with broad stiff midrib and numerous pointed leaflets. When flowering starts, a large, stout spadix emerges from the centre of the crown. Flowers are borne spirally in pairs - one male and the other hermaphrodite but functionally female. The fruit is globose with a very thin endocarp enclosing a single seed.

Propagation is by suckers. For starch extraction the palm is cut down just before flowering when the starch reserves are maximum. The trunk is split longitudinally and the white floury contents scooped out. The material is then washed repeatedly and passed through sieves, dried in the sun or on hot iron trays. Crude sago ferments quickly. A single palm yields about 250-350 kg sago. In the swamp forest groves of Papua New Guinea, there are about 60 palms/ha.

The agroforestry potential of the sago palm is for the swampy areas where it can grow in mixture with other species.

Ruddle, K., Johnson, D., Townsend, P.K. and Rees, J.D. (1978). Palm Sago - A Tropical Starch from Marginal Land. The University Press of Hawaii.

SHEA BUTTER *Butyrospermum paradoxum* (Gaertn.f) var *parkii* (G. Don.) syn. *B. parkii* (G. Don) Kotschy *(Sapotaceae)*

Shea butter, used as a cooking fat, illuminant, medicinal ointment, etc., is extracted from the seeds of the shea butter tree. Shea oil, which is extracted from the nuts exported from Africa, is used in the manufacture of soaps, candles, and in cosmetics.

The shea butter tree is a medium-sized-to-small tree, 7-13 m tall, growing abundantly in the Central and West African savannas. The principal exporters of nuts are Nigeria, Ghana, Senegal, Mali, the Ivory Coast, Upper Volta and Dahomey. Another variety, var. *nilotica*, occurs in Uganda.

The tree is deciduous; leaves are 10-20 x 5-8 cm; flowers sweet-scented and white, borne in clusters at the end of shoots; the fruits mature in 4-6 months, and when ripe they are hard, brown, about 5 cm long with fleshy sweet pulp and are usually single-seeded.

The shea butter tree is adapted to drier parts of the equatorial belt of Central and Western Africa in areas where oil palm does not grow well. Dry lateritic slopes are the best suited; alluvial soils and areas subject to flooding are not preferred.

MISCELLANEOUS PLANTS

Propagation is usually by seeds; since seedlings have a long tap-root, transplanting is often difficult. Field spacing is about 8 m. Trees start bearing fruits in 12-15 years, and full bearing is attained in about 30 years. The fruit is allowed to fall naturally from the tree and then collected. The peak season of maturity is June-September. The collected fruits are allowed to ferment when the pulp decays away. The seeds are then separated and dried; they contain 45-55% fat and 9% protein.

Average yield is 15-20 kg fresh fruit per tree; 100 kg fresh nuts give 40 kg dry seeds. An average of one tree in every three is productive each year.

Shea butter is a good species for agroforestry in the drier margins of the savanna with a very marked (4-6 months) dry season. It has a dense crown, and its cultivation is not labour-intensive.

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GLOSSARY OF TERMS

Abaxial: the side, usually of a leaf, facing away from the stem or the axis (i.e., the underneath surface).

Achne: A dry indehiscent one-seeded fruit with a pericarp that is separate from the testa.

Acuminate: ending in a tapering narrow point with concave sides.

Adaxial: the side, usually of a leaf, turned towards the stem; the upper surface.

Adventitious: not in the usual place; e.g., roots on stems, or buds produced elsewhere than in the axils of leaves or tips of stems.

Alternate: leaves borne at different levels along the stem as distinct from opposite or whorled.

Anemophilous: wind-pollinated.

Annual: a plant that completes its life cycle in one year.

Anther: the part of the stamen that contains the pollen.

Anthesis: process of dehiscence of the anthers; also refers to the time of opening of flower and dispersal of the pollen.

Apomixis: reproduction from an unfertilized egg.

Aril: additional covering or appendage of the seed developing from its stalk.

Asexual: reproduction that does not involve union of gametes; usually vegetative.

Auricle: An appendage, as at the base of the laminae of grasses.

Autogamy: fertilization of a flower by its own pollen.

Awn: A pointed bristle-like organ, as in grass flowers.

Axil: the upper angle between the leaf and the stem.

Axillary: arising from the axil.

Bark: usually refers to all the tissue outside the vascular cambium.

Berry: a simple fleshy fruit with seeds immersed in the pulp.

GLOSSARY OF TERMS

Biennial: a plant that completes its life cycle in the second year or season.

Bilocular: having two compartments or cells.

Bipinnate: a leaf in which the primary pinnae (divisions) are themselves pinnate.

Bisexual: a flower in which both sexes are present and functional.

Blade: refers to the enlarged or expanded part of a leaf or petal.

Bract: a miniature leaf that subtends a flower or flower stalk.

Bulb: a shortened underground shoot or bud having fleshy leaf bases or scale leaves.

Bulbil: small aerial bulb that may form instead of flowers or axillary buds, and which, on separation, can propagate the plant.

Bush: a low thick shrub with no distinct trunk.

Callus: the new tissue produced when a part is injured or severed.

Calyx: the outer envelope of the flower, consisting of two or more carpels.

Capitate: collected into compact head-like clusters.

Capsule: a dry many-seeded dehiscent fruit consisting of two or more carpels.

Carpel: a leafy, spore-producing unit of the pistil or ovary; the pistil many consist of one or more carpels.

Caryopsis: a dry, indehiscent, one-seeded fruit in which the pericarp is closely adhered to the seed.

Catch crop: a short-duration crop grown in the intervening period between two main seasons of the major crop.

Caulifloroue: flowers borne on the stem, usually from the old wood.

Ciliate: hairy along the edge.

Clone: a group of plants developed from the same plant by vegetative propagation.

GLOSSARY OF TERMS

Corm:	a swollen, solid, short, usually rounded, underground stem, covered with scale leaves and buds appearing at the top.
Corolla:	the usually coloured or showy part of the flower consisting of free or united petals.
Cotyledon:	embryonic leaf.
Cultivar: (cv., cvs)	an agricultural or horticultural variety that has originated and persisted under cultivation; usually referred to as "variety", but botanically a variety is distinct from a cultivar.
Cyme:	a determinate inflorescence with sympodial branching; with the main axis ending in a flower.
Deciduous:	usually refers to leaves, but also to flowers, that are falling off or subject to fall.
Decumbent:	lying on the ground, reclining.
Dehiscent:	opening up spontaneously when ripe.
Determinate:	the prolongation of the stem or inflorescence stalk stops when the terminal or the central flower of an inflorescence opens.
Dichotomous:	partitioning regularly into two.
Dicotyledon:	angiosperms with two cotyledons.
Digitate:	a leaf with leaflets originating from the same point like the fingers of a hand.
Dimorphic:	having two forms or types, e.g., branches.
Dioecious:	plants with unisexual flowers; male and female flowers on different plants.
Distal:	farther from the point of attachment.
Distichous:	regularly arranged on either side of the stem.
Dorsal:	refers to the back or outer surface.
Drupe:	a fleshy, indehiscent, single-seeded fruit, in which the endocarp forms a strong encasement of the seed.
Elliptic:	oval shape with rounded ends.
Embryo:	normally develops from a fertilized egg and consists of a rudimentary plant still in the seed.

GLOSSARY OF TERMS

Endocarp:	the innermost layer of the fruit wall or pericarp.
Endosperm:	food reserve tissue enclosing the embryo and developed from the fertilized fusion nucleus.
Ensiform:	sword-shaped.
Entire:	an even margin without serrations.
Epicotyl:	the stem above the cotyledons.
Epigeal:	above ground; when cotyledons are raised above the ground in germination.
Epiphyte:	a plant which grows on another plant but without deriving nourishment from it.
Exocarp:	the outer layer of the pericarp.
Falcate:	sickle-shaped.
Fascicle:	a cluster of organs (leaves, flowers, etc.) originating from the same point.
Filiform:	thread-like, slender.
Flabellate:	fan-like.
Flexuose:	zigzag.
Floret:	individual minute-to-small flower.
Follicle:	a dry dehiscent fruit of a single carpel.
Fruit:	the structure that develops from the ripened ovary; but the term is used loosely to denote structures formed from other components also.
Frutescent:	shrubby.
Fusiform:	spindle-shaped, tapering at each end.
Gamopetalous:	with petals that are united either completely or partially.
Genotype:	an organism comprising the sum total of its genes, or a group of organisms with the same genetic make-up.
Glabrous:	hairless.
Glaucous:	of greyish or greenish blue that rubs off.
Gynaecium:	collective name for the pistil(s) in the flower.

GLOSSARY OF TERMS

Halophyte:	a plant that is more tolerant of mineral salts, especially sodium, in excess of the usual levels.
Haustorium:	an absorbing organ.
Herb:	a non-woody vascular plant.
Hermaphrodite:	bisexual; stamens and pistil in the same flower.
Heterogeneous:	not uniform.
Hilum:	the scar on a seed indicating its point of attachment.
Hirsute:	with coarse stiff hairs.
Homogeneous:	showing no variability.
Husk:	outer covering of some fruits.
Hypocotyl:	the part of the stem that bears cotyledons.
Hypogeal:	below ground; cotyledons remain below the ground in germination.
Inflorescence:	a group of flowers having a definite arrangement and mode of development on the floral axis.
Lamina:	the blade or expanded portion, mostly of the leaf, but also of the petal.
Lanceolate:	long with a wide base and tapering apex.
Ligule:	a thin membranous organ projecting from the top of the leaf-sheath of grasses.
Lobed:	partitioned but not distinctly as leaflets.
Male sterility:	when pollen is absent or non-functional in flowering plants.
Mesocarp:	the middle layer of the pericarp developing into the fleshy and succulent part.
Midrib:	the prominent vein on the leaf as a continuation of the petiole.
Moniliform:	like a string of beads.
Monocotyledon:	angiosperm with a single cotyledon.
Monopodial:	when the primary axis continues its original line of growth to produce successive lateral branches.

GLOSSARY OF TERMS

Mycorrhiza:	a symbiotic association between a fungus and a root forming a structure outside the root (ectotrophic) or within the outer tissues (endotrophic).
Nut:	a dry indehiscent one-seeded fruit with a woody pericarp.
Oblong:	more long than broad with almost parallel sides.
Obovate:	ovate to egg-shaped with the top half broader than the basal half.
Obtuse:	blunt at the end.
Opposite:	when referred to leaves or branches: two are borne at the same node on opposite sides of the stem.
Orthotropic:	vertically elongating.
Ovary:	the basal portion of the pistil covering the ovules and eventually becoming the fruit.
Ovoid:	solid object that is egg-shaped in section.
Ovule:	the structure containing the egg and developing into seed after fertilization.
Palmate:	divided like the palm of the hand.
Panicle:	an indeterminate racemose inflorescence with spikelets and stalked flowers.
Paripinnate:	a pinnate leaf with an odd terminal leaflet.
Parthenocarpic:	producing fruit without pollination.
Pedicel:	stalk of an individual flower.
Peduncle:	the main (and also secondary) axis of the inflorescence.
Pendant, Pendulous:	hanging down; drooping.
Pepo:	the berry-like fruit of *Cucurbitaceae*.
Perianth:	the floral 'leaves' as a whole (sepals and petals).
Pericarp:	the fruit wall; it can be sometimes divided into exocarp, mesocarp and endocarp.

GLOSSARY OF TERMS

Petal:	leaf-like structure forming a segment of the corolla; usually brightly coloured.
Petiole:	leaf stalk.
Phenotype:	physical or external appearance of an organism, as distinct from the genotype.
Phloem:	food-conducting tissue of the stele.
Phyllode:	flat thick petiole functioning as a leaf.
Phyllotaxy:	arrangement of leaves (or floral parts) on their axis.
Pinna(e):	primary leaflet of a pinnate leaf.
Pinnate:	a compound leaf with the leaflets (pinnae) arranged along each side of a common rachis.
Pistil:	the female parts of a flower, which when complete consists of the ovary, style and stigma.
Pistillate:	a unisexual flower with pistil but not stamens.
Pith:	the central part of the stem or root enclosed in a hollow vascular cylinder.
Placenta:	cushion-like part of the ovary to which the ovules are attached.
Plagiotropic:	lateral branches heading away from the vertical plane.
Plumose:	feather-like, with fine hairs.
Plumule:	the primary bud of a germinating seed: syn. Epicotyl.
Pollen:	male reproductive element (grains) borne on the anthers.
Precocious:	appearing or developing early.
Procumbent:	lying loosely on the ground surface.
Protandrous:	pollen being shed before the stigma is receptive.
Protogynous:	stigma being receptive before the pollen is shed.
Pubescent:	covered with short soft hairs.
Raceme:	an unbranched, indeterminate, elongate inflorescence with pedicelled flowers.

GLOSSARY OF TERMS

Rachis:	the main axis of an inflorescence.
Radicle:	the first root of a germinating seed.
Ratoon:	new shoots that are produced after the first crop, which can be used for subsequent crops from the same plant.
Receptacle:	the tip of the pedicel into which the floral parts are attached.
Reniform:	kidney-shaped.
Reticulate:	netted as in the case of smallest veins of a leaf.
Resin:	oxidation product of various essential oils.
Rhizome:	an underground stem that usually grows just below the surface, and is distinguished from the roots by the presence of nodes, buds, and scale leaves.
Rootstock:	a seedling or other plant upon which the scion is budded or grafted.
Rostellum:	a small beak.
Runner:	a slender trailing shoot with roots.
Scutellum:	another name for the single cotyledon of monocotyledonous plants.
Self-pollination:	pollination with pollen from the same flower or from other flowers of the same plant.
Self-sterile:	failure to complete fertilization after self-pollination.
Sepal:	a segment of the outermost floral whorl, usually green in colour.
Septate:	divided by one or more partitions.
Serrate:	saw-toothed.
Sessile:	stalkless.
Seta:	a stiff hair or bristle.
Sett:	a short stem cutting used for propagation.
Shrub:	a woody plant of small size and low branching.
Simple:	when referring to leaves, not divided or compound.

GLOSSARY OF TERMS

Sinus: the depression between two lobes or teeth.

Spadix: a racemose inflorescence similar to a spike, but with a swollen fleshy peduncle to which sessile flowers are attached.

Spathe: a large bract enveloping the whole spadix.

Spicate: spike-like.

Spike: a simple indeterminate inflorescence with sessile flowers along a single axis.

Spikelet: a small spike consisting of one or more flowers with a common pair of glumes, as in grasses.

Spine: a stiff, short, pointed, hard structure.

Stamen: a unit of the male reproductive organ of the flower.

Staminate: a unisexual flower with stamen but not pistil.

Stigma: the pollen-receiving part of the pistil.

Stipel: small secondary stipule at the base of a leaflet of a compound leaf.

Stipule: a small leaf-like structure at the base of a leaf petiole.

Stolon: a slender stem runner trailing above the ground and producing at the nodes roots and buds capable of reproducing the plant.

Style: the part of the pistil that connects the ovary with the stigma.

Sympodial: refers to a stem in which the growing point either dies or produces an inflorescence, the growth being continued by a new lateral growing point.

Syncarpous: an ovary composed of united carpels.

Tendril: a slender, thread-like climbing organ formed from the stem or leaf.

Terminal: at the tip of a stem and limiting its growth.

Testa: the seed coat developed from the integument.

Tiller: a shoot from the lower leaf axils.

Tomentose: thickly covered with soft hairs.

GLOSSARY OF TERMS

Truncate:	more or less squarely cut at the end.
Tuber:	swollen underground stem or root that constitutes a storage organ that can also be used for propagation, and that usually lasts one year.
Umbel:	a racemose, indeterminate, flat-topped inflorescence with suppressed puduncle and pedicels arising from a common point.
Unilocular:	having a single cavity.
Venation:	arrangement of veins of a leaf.
Ventral:	the surface (of a leaf) towards the axis; front.
Verticillate:	several leaves arising in a whorl from the same node.
Viability:	ability to live and develop.
Xerophyte:	a plant that is adapted to conditions of limited water supply.
Xylem:	the conductive tissue for water with minerals in the stele.
Zygote:	a fertilized egg.