Guide to Cultivated Plants

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Foreword

Working in agriculture – whether in education, research, advisory or more practical roles – requires a thorough knowledge of the morphology, botany, ecology, agronomy and use of cultivated crops. This is well recognized, and almost all education programmes in Agriculture, Agronomy, Crop Science, Plant Breeding and related subjects offer mandatory courses to ensure that students acquire such knowledge.

The authors of this book share about 80 years of experience in educating students in these aspects of crop plants. They have often been the first teachers in crop science-related courses that students met in Wageningen, and Koop Wind and Ton Elzebroek have taken their teaching assignments seriously showing both great professionalism and enthusiasm. Their courses were always based on up-to-date written material produced by themselves and they continuously improved the quality of their courses and the hand-outs to the wishes of a dynamic population of students. The quality of their teaching was always clear from the very positive student evaluations of their courses. We often meet former students who have vivid and warm memories of these courses.

When Koop and Ton were approaching retirement we recognized the need to capture their knowledge and experience in the form of a book and we are very glad that they took up the challenge. The product is now in your hands and we – the undersigned – are proud of it.

The book includes 346 crop species, of which 180 are described in some detail. There are 92 main entries comprising 11 commodity groups ranging from vegetables grown in horticulture to forages species and arable crops grown in arable farming systems, to the major fruits and plantation crops. All major crops from temperate, Mediterranean and tropical climates are included. The book contains 370 figures, of which about three-quarters are in full colour.

It is certainly not the first book on this topic and it most likely will not be the last. This book, however, is unique because of the consistency of the

descriptions based on a well thought-over outline design, the beautiful illustrations (both pictures and drawings) and the fact that it is obviously written with pleasure, dedication and most of all love for the subject, with an enormous input of time and effort.

We congratulate the authors and the publisher on this product and do hope that readers will enjoy it as much as we do.

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Preface

This book is a standard reference text for students of (agricultural) universities and colleges, extension workers, teachers, farmers, horticulturists and in general for all those who are interested in cultivated plants. Although various monographs of cultivated plant species and multivolume handbooks such as *Tropical Crops* by J.W. Purseglove and the PROSEA (Plant Resources of South-East Asia) handbooks have been published, this book provides concise textual descriptions and attractive illustrations of around 100 entries in a single handbook. Depending on their importance, each entry consists of either a single species, as in the case of potato and rice, or of a group of related species, such as the yams, millets and labiate spices.

The selection of plants is mainly based on their relative importance in terms of cultivated area and economic value. Information on production of the crops is derived from statistical databases concerning 'Primary Crops of Agricultural Production', from the Food and Agriculture Organization of the United Nations. Consistent with this list, commodity groups such as timber trees and forestry plants, ornamental plants, dye- and tannin-producing plants and medicinal plants are not included.

The selected cultivated plants are classified according to their main usage, in the following commodity groups: Beverages and Tobacco; Edible Fruits and Nuts; Elastomers; Fibre Crops; Forages; Oil Crops; Protein Crops; Spices and Flavourings; Starch Crops; Sugar Crops; and Vegetables. The various plants or groups of plants are described conforming to a certain format, including their origin, history and spread; botanical characteristics; cultivars (or varieties), uses and constituents; and ecology and agronomy. Except for specific examples which have major effects on production, the description of diseases and pests and their treatments are not included. Moreover, this subject is more suitable for a separate and detailed description.

To improve the readability of the book, the scientific names of plant species are used without their scientific authorities; these can be found in the index of plant names.

The majority of the described cultivated plants are food plants. Their importance for food supply and food security, now and in the future, is evident.

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The authors would like to pay special thanks to Professor Rudy Rabbinge (University Professor) who initially proposed the writing of this book, Professor Ken Giller (Plant Production Systems Group), Professor Paul Struik (Crop and Weed Ecology Group) and Emeritus Professor Marius Wessel (Tropical Agriculture), from Wageningen University and Research Centre (WUR), for their advice and suggestions in the preparation of this book. Their judgements concerning the content have proved to be invaluable.

We are grateful to Ir. Dirk L. Schuiling for making available the interactive computer program TROPCROP, which he developed for use in the study of tropical and subtropical cultivated plants. During the realization of this book we often had inspiring conversations with Mr Schuiling, which resulted in improvement of the content.

We thank the Board of the PROSEA Foundation (Plant Resources of South-East Asia) who made available a great number of botanical line drawings originally made for illustrating the series of PROSEA books; Piet Kostense, Harry Wijnhoven and Dick van de Gugten, who contributed to making line drawings; PPO–AGV Lelystad for lending us several slides concerning lettuce and endive; Jan Oude Voshaar from the Wageningse Berg vineyard and Patrick Hendrickx of the Mushroom Research Group of WUR, who contributed to the sections regarding grapes and mushrooms. Several slides were derived from the personal archives of actual and previous staff members of WUR.

As well as using the botanical line drawings of PROSEA, we often consulted their books, which proved to be an important source of information. Also, information regarding cultivated plants in the *Handbook of Energy Crops* (J.A. Duke), published only on the World Wide Web, was very useful to us. Most of the statistics used are derived from statistical databases concerning 'Primary Crops of Agricultural Production', from the Food and Agriculture Organization of the United Nations (FAO).

Photographs and line drawings used without mention of the source are derived from the WUR archive.

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1 Beverages and Tobacco

Cacao

Cacao – *Theobroma cacao;* Sterculia family – *Sterculiaceae*

Origin, history and spread

The origin of the cacao tree is thought to have been in the lower tree storey of the evergreen tropical rainforests of the upper Amazon basin. It is assumed that in early times a natural population of cacao was spread throughout the central part of the Amazon, as well as along the Orinoco River towards Venezuela and the Guyanas, and west- and northwards to the south of Mexico. These populations developed into two distinct forms, geographically separated by the Panama isthmus: the Criollo type found in Central America and the Forastero type found in the upper and lower Amazon basin. The Criollo type of cacao was already grown by the Aztecs and Mayas in Central America but there is no evidence that the Forastero cacao was cultivated until the Spaniards started to extend the cultivation of cacao in South America. Until the end of the 18th century cacao production was dominated by the Criollo type.

The continuous increase in cacao cultivation in South America resulted in two separate Forastero types: the Amelonado Forastero type in the Brazilian state of Bahia, originating in the lower Amazon basin, whereas the 'Nacional' Forastero type in Ecuador originated in the upper Amazon basin.

The Trinitario type is a natural hybrid between the Criollo and Forastero types and replaced the earlier Criollo type on Trinidad after 1800. The Portuguese successfully transferred Forastero cacao to West Africa in the 19th century, where it gave rise to the West African Amelonado variety. The first introduction of cacao to South-east Asia can be traced back to the few Criollo seedlings taken from Central America to the Philippines by the Spanish around

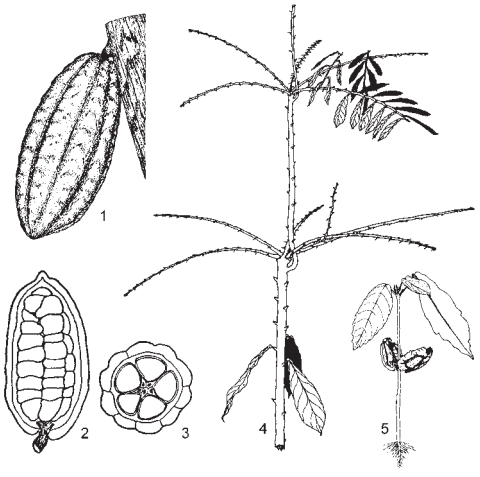

Fig. 1.1. Cacao: 1, fruit ('pod'); 2, fruit in longitudinal section; 3, fruit in cross-section; 4, dimorphic branching habit of young tree; 5, seedling.

the year 1670. The Dutch introduced cacao into Indonesia in the 17th century. Cacao is cultivated now throughout the per-humid and humid tropics, especially in West Africa and South-east Asia.

Botany

Cacao (Fig. 1.1) is an evergreen tree 4–20 m tall, although in cultivation usually 4–6 m. The tap root grows up to 2 m straight down with most of the (up to 6 m long) lateral roots in the upper 20 cm soil layer. Cacao roots are possibly colonized with a mycorrhizal fungus. The main stem of a young cacao plant may grow to 1–1.5 m in height before branching. The stem growth is sympodial, with orthotropic subterminal shoots (chupons) and lateral branching with successive whorls (fan or 'jorquette') of plagiotropic branches. However, the dimorphic branching in cacao is not as absolute as in coffee species; orthotropic shoots can be induced on mature plagiotropic stems.

The leaves are simple, petiolate, usually glabrous, elliptical oblong, 15–50 cm × 4–15 cm. The leaves are produced in flushes; soft and pendulant when young, dark green and leathery at maturity. The petiole is 1–10 cm long with a well-marked pulvinus at both ends. The leaves of the main stem and chupons are spirally arranged, while the leaves on branches are alternate. The stipules at the base of the petiole are shed as the leaves mature.

Inflorescences are borne on leafless older trunk and fan branches (cauliflorous), usually borne on small flower cushions (tubercles) in short, many-flowered fascicles; flowers are five-parted, hermaphrodite, white to reddish and 1–1.5 cm in diameter; pedicels 1–2 cm long. The five sepals are pink or whitish, triangular and rather fleshy; the petals are smaller than the sepals, 3–4 mm long, expanding into a concave, cup-shaped pouch, white with two prominent purple guide lines; upper part spatulate, pale yellow and reflexed. The male part of the flower (androecium) consists of an outer whorl of five long, pointed staminoides, and an inner whorl of five fertile stamens, standing opposite the

petals. The ovary is oblong-ovoid, superior, with five carpels. The style is partially divided into five lobes (Fig. 1.2).

A full-grown tree may produce more than 10,000 flowers/year of which perhaps only ten to 50 will develop as mature fruits. Pollination is effected by insects, particularly by specific flying female midges. Unpollinated flowers abscise within 24 h. During the first half of the period of pod development, part of the young fruits (cherelles) stops growing, blackens and shrivels. This fruit thinning process is called 'cherelles wilt'.

The fruit is a berry-like drupe, commonly called a 'pod', with a lignified, smooth or furrowed fruit wall (husk). The 20–60 seeds, usually called 'beans', are embedded in a mucilaginous, whitish and sweet pulp. At maturity the seed consists of two large cotyledons, a small embryo and a leathery skin or shell (testa). The 1000-seed weight, at 30% moisture content, is about 2 kg.

Uses and constituents

At the time the Spaniards conquered Mexico in the early 16th century, they found the cacao tree in the south of the country, where it had already been expertly cultivated for centuries. In Central America the valuable cacao beans were used both as currency and for preparing an invigorating beverage, called 'cacahuatl', by boiling a mix of ground roasted cacao beans with maize, vanilla and chilli peppers.

The Maya Indians considered the plant to be of divine origin. The mythological prophet Quatzalcault took the seeds from paradise and planted them in his garden at Talzitepic. By eating the fruits he acquired universal knowledge and wisdom, which brought him great adoration. The name '*Theobroma*', given by Linnaeus and meaning 'food of the gods', is derived from this legend.

Fig. 1.2. Cacao: cauliflorous inflorescences (left) (photo: J. van Zee) and close-up of a single flower (right) (photo: D.L. Schuiling).

The Spaniards found that cacao beans could be made into a more palatable drink when mixed with sugar and in this form it became popular in Spain, from where it spread to France and England in the 17th century and successively to other European countries. During the 17th and 18th centuries it remained an expensive drink to consume, for instance in the chocolate houses of the aristocracy in London.

The invention of the cacao press, by C.J. van Houten in The Netherlands in 1828, to extract most of the cacao butter, and the process to manufacture milk chocolate, invented by M.D. Peter in Switzerland in 1876, had major impacts on the increase in consumption of cacao products. At the same time the cacao tree was increasingly introduced into many countries.

The manufacture of chocolate consists of various phases. Before the cacao beans (more accurately the seeds) enter international trade, they are fermented and dried in the producing countries. During the process of fermentation, with limited aeration, the mucilage around the seeds breaks down and purple pigment diffuses through the cotyledons. The precursors of the chocolate flavour are produced when the protein and polyphenol compounds react with enzymes, and the astringency disappears. After fermentation the beans are dried in the sun. The beans should be covered during rain and often for the hottest part of the day. The dried beans are normally packed in jute bags and shipped in containers. Once the dried beans have arrived in the chocolate-producing countries, the beans are roasted, after which the full cacao flavour develops. More than 60 aromatic compounds have been found to contribute to cacao flavour.

The roasted beans are ground to cacao mass (also known as 'cacao liquor'). Then cacao butter (fat) is pressed out of part of the cacao mass, lowering the fat content from 55 to 24%; another part of the mass is kept aside. The press cake is ground to powder. Then part of the cacao butter (and sugar) is added to the kept cacao mass to get plain chocolate or, after adding milk, to get milk chocolate. The base of white chocolate is cacao butter only. The cacao powder, when mixed with milk and sugar, makes a very nutritious beverage and the presence of theobromine and caffeine causes a mildly stimulating action.

Chocolate is rich in energy and provides a concentrated food with excellent keeping quality. A typical bar of milk chocolate may contain 15% cacao liquor, 20% cacao butter, 22% milk solids, 40% sugar, small amounts of lecithin emulsifier and vanillin, about 30 mg of caffeine (a cup of coffee contains 100–150 mg of caffeine) and about 44–60 mg of theobromine.

It is suggested that the substantial amount of sugar may partly explain chocolate's supposed addictive properties. On the other hand, scientists reported recently that chocolate may keep high blood pressure down, due to the presence of flavonoids. In general plain chocolate is higher in flavonoids than milk chocolate. During the manufacturing of cacao powder and cacao drinks, most of the flavonoids are removed.

It is possible for a person to be allergic to chocolate, but recent evidence suggests that the assumed allergen property of chocolate is rarer than generally is believed. Chocolate can be toxic, or even fatal, for pets in general but especially for dogs because they like to eat it.

Ecology and agronomy

Cacao is strictly a tropical crop and thrives best in the lowland areas of tropical evergreen and semi-evergreen rainforests. The limits of cultivation are 20°N and S, although the bulk of the crop is grown within 10°N and S. It can be grown at higher altitudes only if other conditions are favourable. Most cacao is grown in areas with an annual rainfall of 1500–2500 mm, with no more than three consecutive months of rainfall less than 100 mm. The optimum temperature ranges between a mean maximum of 30–32°C and a mean minimum of 18–21°C. The absolute minimum temperature should not be below 10°C. Cacao requires well-drained, deep and fertile soils with at least 2% organic carbon and a soil pH of about 6.5. Soils with a large moisture-storing capacity can compensate for periodic drought. Although the wild cacao tree is adapted well to dense shade conditions, it does not necessarily mean that mature cacao, grown as an economic crop, requires such low light intensities (Fig. 1.3).

The cheapest and most practised method of propagating cacao is by seed. Seeds are produced in biclonal gardens by open or controlled pollination to obtain 100% legitimate hybrid seed. Vegetative propagation is used mainly in breeding programmes and for establishing seed gardens. Seedlings are raised in a shaded nursery, usually in polythene bags. Young seedlings sometimes form double stems of which one has to be removed. When the seedlings are 4–6 months old, they are transplanted to the field at densities of 1100–1200 trees/ha. During transplanting damage to the tap root should be avoided. Young cacao seedlings require shade. When the trees grow older and have a sufficiently developed canopy the need for shade decreases. Once the canopies of

Fig. 1.3. Cacao pods hanging from trees under almost closed canopy.

neighbouring trees have met, little or no shade is needed. However, light conditions should be considered in relation to other growth conditions; when these are suboptimal, shade trees are still required. Shade can be provided either by thinning forest or by planting shade trees such as the leguminous species *Gliricidia sepium* and seedless clones of *Leucaena leucocephala*. Cacao is often grown with other crops such as coconut, oil palm and fruit trees.

Weeding is needed during establishment, preferably by slashing without scraping the topsoil in order not to damage the root systems of cacao. The remaining mulch also reduces the evaporation loss from the soil. Once the cacao trees mature, weed growth is suppressed by heavy shade beneath the canopy. Removal of basal chupons is often combined with weeding. Weed control is also done by the use of herbicides, especially when noxious and persistent weed species occur. Cacao is very susceptible to pests and diseases. In particular, sap-sucking mirids feeding on the stem tissue of young twigs may cause progressive deterioration of the canopy and require insecticidal control. Among the diseases, *Phytophtora* pod rot causes large economic losses. Especially in high-rainfall areas, spraying with copper fungicides is needed.

Fertilizer requirements depend to a great extent on soil fertility, age of trees, yields and shade; lightly shaded and unshaded cacao requires more fertilizers, particularly nitrogen. Soil analyses give a better diagnostic value than leaf analyses. Nutrients removed by 1 t of cured cacao beans are 20 kg N, 4 kg P and 10 kg N. As a general guide, per hectare, mature cacao needs 50–100 kg N, 25 kg P, 75 kg K and, sometimes, 15 kg Mg/year.

Young trees need no pruning during the first 2 to 3 years. Later, low drooping branches should be removed to ensure easy access for harvesting and spraying for disease and pest control. The number of fan branches formed at a jorquette is usually four or five. To retain trees at the desired height, chupons should be removed at regular intervals.

In many countries harvesting is extended over the whole year. However, in countries with pronounced wet and dry seasons, the main harvest takes place 5 or 6 months after the start of the wet season. This time interval corresponds with the time required from flower fertilization to fruit ripening. The main harvest lasts for about 3 months, although the crop pattern is also affected by the variety of cacao. Ripe pods are recognized by the colour change. Green-podded Amelonada turn yellow and red pods usually turn an orange shade. The pods remain in a suitable condition for harvesting for 2–3 weeks and have to be cut off the trees with a sharp knife to prevent damage of the flower cushions. Special long-handled tools are used for removing pods which are higher up on the tree.

After harvest, the pods are usually gathered at one or more convenient places, where they are opened and the beans and mucilage are removed. This is preferably done within a few days. The wet beans and mucilage are transferred to wooden boxes for fermentation for 2–4 days for Criollo and Trinitario, or 4–6 days for Forastero cacao (Fig. 1.4). Differences in fermentation and drying methods may result in different qualities of the dried beans. The biochemical effect of fermentation on the quality of the cacao beans is described in the previous section.

Fig. 1.4. Heaps of harvested cacao pods and pulp-enveloped seeds (left) (photo: W. Gerritsma); sun-dried fermented cacao 'beans' (right) (photo: D.L. Schuiling).

The first harvest may take place at the end of the second or third year after planting and increases to a maximum after 10–12 years. Under good growing conditions, a cacao plantation is expected to maintain such yields for 10–15 years. In 2005 the world average yield of dried cacao beans was around 560 kg/ha, with national annual yields per hectare ranging from 490 kg (Ghana), 740 kg (Ivory Coast) to 1250 kg (Indonesia). These data include the yields of smallholder farms and estates. Much higher yields on estates (1500–3000 kg/ha) are no exception. The world production of dried cacao beans was 3.9 million tonnes in 2005. Almost 70% of this total was produced in West Africa, with Ivory Coast, Ghana and Nigeria as main producers. The most important cacao-importing countries are The Netherlands, the USA, Germany and Malaysia.

Coffee

Coffee – *Coffea arabica, Coffea canephora;* Madder family – *Rubiaceae*

Origin, history and spread

Arabica coffee is native to the Ethiopian highlands; wild populations can still be found in the undergrowth of the rainforests in south-western Ethiopia at altitudes between 1400 and 1900 m. Since ancient times, Ethiopian people used to masticate coffee fruits because of the sedative effect of caffeine. Arabica coffee was already cultivated in the 12th century in Yemen. Coffee was brought to Arabia at least in the 15th century, when the discovery of brewing coffee from roasted seeds was made. Arabian traders took it to Europe, India and Ceylon in the 16th and 17th centuries. The Dutch introduced *Coffea arabica* plants, probably originating from Yemen, into Java in 1690. One plant from Java was

brought to Amsterdam in 1706. Coffee is self-fertile, so when the plant in Amsterdam flowered, it could subsequently fruit and produce seeds. The Mayor of Amsterdam gave some of the seeds to the French king Louis XIV. In Paris, new coffee plants were bred from this seed. Offspring of these plants were introduced into Martinique in 1720 and subsequently into Jamaica in 1730. Offspring of the plant in the Amsterdam botanic garden were sent to the former Dutch colony of Surinam in 1718; from there plants were taken to French Guyana in 1722 and to Brazil in 1727. From these introductions it was spread widely throughout the Caribbean and Central and South America. Offspring of the Amsterdam plant were also introduced to the Philippines, Hawaii and Africa. Thus, much of the Arabica coffee originated from one plant in Amsterdam, which means that genetic variability was very limited; all the coffee just mentioned belongs to *Coffea arabica* var. *arabica* (syn. var. *typica*). The French took another variety from Yemen, *Coffea arabica* var. *bourbon*, first to the island of La Réunion (formerly called 'Bourbon') in 1715, and later to Latin America and Africa. The variety *bourbon* has a more compact and upright habit than variety *arabica*.

Due to diseases, especially coffee leaf rust (*Hemileia vastatrix*) in Asia, cultivating Arabica coffee became difficult. Therefore, around 1900, much of the Arabica coffee in Asia was replaced by another coffee species, *Coffea canephora*, also called 'Robusta coffee', which was resistant to coffee leaf rust. Robusta coffee is native to the equatorial lowland forests from Guinea to Uganda. Robusta coffee was first introduced into Java. It is now widely grown in the tropical lowlands of South-east Asia, in South America and also in Africa. Arabica coffee is now mainly cultivated in tropical high-altitude areas of South-east Asia, in South America and in Africa. Today about 75% of the world's coffee comes from Arabica coffee.

Botany

Coffee (Fig. 1.5) is an evergreen, glabrous, multi-stemmed shrub or tree, up to 12 m tall; in cultivation pruned to about 2.5 m. The leaves are opposite, simple, dark green, shining, elliptic-ovate, 6–12 cm × 4–8 cm, with prominent veins, and margins somewhat undulate. They have an acuminate apex and a short petiole, about 2 cm; the leaves have connate, subtriangular stipules. The inflorescence consists of an axillary cluster of cymes. There are ten to 30 flowers per node. The flower is bisexual and consists of a small, cup-shaped, green calyx with four to eight lobes; a white, tubular, five- to eight-lobed corolla, 1 cm long and 1–1.5 cm in diameter; the stamens are inserted in the throat; the ovary is inferior, two-celled, with one ovule per cell. Flowers have a jasmine-like scent; they open simultaneously. The fruit is a drupe (in coffee mistakenly often called a 'berry'), about 1.5 cm long, oval-elliptic, the exocarp green when immature, turning yellow first, then red to purple at maturity and black upon drying. Embedded in the fleshy mesocarp there are usually two ellipsoidal, deeply grooved seeds, pressed together and flattened on one side, with horny endocarp. The seed (in coffee mistakenly often called a 'bean') contains mainly endosperm and a small embryo (Fig. 1.6). The 1000-seed weight is 400–500 g.

Fig. 1.5. Arabica coffee: 1, twig with flowers and fruits; 2, flower; 3, stipule; 4, fruit; 5, seed (line drawing: PROSEA volume 16).

The root system is relatively shallow, taproot only up to 1 m deep or less, although some laterals may grow up to 4 m deep for solid anchorage; by far most of the feeding roots are located in the top 30–40 cm of the soil.

Robusta coffee differs from Arabica coffee in some features: it is a more vigorous-growing and taller tree, up to 12 m. Robusta coffee has larger leaves, 15–30 cm × 5–15 cm, and more flowers, up to 80 per node.

Cultivars, uses and constituents

Many cultivars or varieties exist. Popular ones, especially in Brazil, are for example the already mentioned 'Typical' and 'Bourbon'; furthermore 'Mundo Novo' and 'Caturra'. Over 30 mutants are known; breeders have developed many cultivars with resistances such as disease resistance and cold resistance. Some cultivars produce only one instead of two seeds per fruit. Recently, Brazilian scientists identified an Arabica coffee that naturally contains very little caffeine, 0.76 mg instead of the normal 12 mg/g of dry mass; and it does not influence the taste. This discovery is very important for breeding programmes to develop 'healthier' cultivars.

The dried seeds are roasted, ground and brewed to produce one of the most important, stimulating, well-flavoured, non-alcoholic beverages in the world. The stimulating effect is caused by the alkaloid caffeine; the flavour comes from the essential oil caffeol and sugar. The characteristic coffee aroma is only brought out after roasting and grinding the seeds. Coffee is also widely used for flavouring ice cream, desserts, pastries and liqueurs. Coffee is usually marketed

Fig. 1.6. Arabica coffee: 1, flower cluster; 2, clusters of ripe berries; 3, cross-section of berry; 4, dried seeds with silver skin (testa).

unroasted, in sacks. Roasting is mostly carried out by coffee companies in the importing countries. After roasting, especially in Europe, various blends can be made, mainly from Arabica coffee and Robusta coffee. Although the quality of Arabica coffee is better than that of Robusta coffee, the latter is in great demand due to its stronger flavour and the higher yield of soluble solids, which is important for the manufacture of instant coffee. Instant coffee is a soluble powder, prepared by dehydrating extracts of roasted and ground coffee. A third coffee species, *Coffea liberica*, contributes only about 1% to the world coffee production. Its taste is more bitter than that of the other coffee species. It has only local importance.

The coffee consumer can buy coffee as vacuum-sealed packets of whole roast 'beans' or ground 'beans', or several forms of instant coffee. Dried coffee 'beans' contain approximately 10–13% water, 11–16% proteins and free amino acids, 12–14% lipids, 5–9% sugars, 32–48% polysaccharides, 10–15% acids and 4% ash and minerals. The caffeine content ranges from 0.6 to 3.3% and the essential oil content from 10 to 13%. During roasting at recommended temperatures of 200–250°C, the sugars caramelize, the polysaccharides carbonize

and the typical aroma is released. The roasting must take place in the consumer country, because roasted coffee quickly loses its aroma.

In Africa ground roasted coffee is sometimes eaten mixed with fat or butter. In the Middle East, fermented coffee pulp is used to prepare a drink. Coffee pulp is also used as manure and mulch, or fed to cattle. In The Netherlands, traditional candies called 'Haagse hopjes' are made from coffee extract.

In folk medicine, coffee is used to treat many different ailments; for example, it is reported to be antidotal, diuretic, hypnotic, stimulant, cardiotonic, and a remedy for asthma, fever, malaria, headache and many more.

Ecology and agronomy

Arabica coffee thrives on deep (2 m), well-drained, slightly acid fertile loams, or clay loams of volcanic origin with pH 5.3–6.6. It is an upland species. The ideal conditions for growth can be found around the equator at altitudes of approximately 1000–2000 m, or lower altitudes from 300 to 1000 m when further from the equator. The average day temperature has to be 18–22°C, with a well-distributed annual rainfall of about 2000 mm. A drier period of 2–3 months is required for initiation of the flower buds. Lower rainfall should be compensated for by irrigation.

Robusta coffee is primarily a tropical humid lowland species. It is adapted to warm equatorial climates with average day temperatures of 22–26°C, and well-distributed annual rainfall of 2000 mm or more, but is also successfully grown in tropical climates with a 2–3-month dry season. Unlike Robusta coffee, Arabica coffee is grown under light shade. As Arabica coffee is self-pollinating, it can be propagated from seed and still keep uniformity. Robusta coffee is also often propagated from seed, but because the species is cross-pollinating, the seed has to be produced in biclonal or polyclonal gardens without other coffee varieties around. Apart from seed, budding, grafting and cuttings have been used for propagation. Today, *in vitro* multiplication, including micro-propagation, is applied as well. Grafts, cuttings and seedlings are usually raised in shaded nurseries. At 6–12 months, when the young plants have four to six leaf pairs, they are transplanted to the field at densities of 1300–2800 trees/ha for Arabica and 1100–1400 for Robusta. Cultivars with a more compact growth habit, like 'Caturra' and certain hybrids, can be planted at high densities of 3000–5000 trees/ha. Planting holes are usually filled with a mixture of topsoil, manure and phosphate. Young plants are very sensitive to weed competition. Weed control methods involve regular manual weeding, application of herbicides, mulching and planting of cover crops.

In Africa coffee is often grown by smallholders, but in countries like Brazil larger plantations are found (Fig. 1.7). Young trees are often intercropped with food crops or cover crops. Fertilizers are commonly used in plantations. Requirement can accurately be determined by foliar analysis and by nutrient removal of the crop. One tonne of dried green 'beans' removes about 35 kg N, 3 kg P, 40 kg K, 3 kg Ca, 2 kg Mg, and some Fe and Mn. Commonly recommended annual fertilizer rates per tree are of the order of 175 g N, 100 g P and 175 g K. Regular pruning is required. This is connected with the specific growth

Fig. 1.7. Three-year-old Arabica coffee plantation with fruiting shrubs, Campinas, Brazil.

and development model of coffee whereby each plagiotropic (horizontal) branch node flowers only once (Fig. 1.8), so that in the course of time fruiting moves towards the tip of older branches and the newly formed branches higher up on the constantly growing orthotropic (vertical) stem. To restrict tree height and maintain vigour in the basal parts, strict rejuvenation pruning is needed, usually

Fig. 1.8. Detail of fruiting, plagiotropic branches of Robusta coffee (photo: W. Gerritsma).

by allowing several vertical shoots to grow and replacing them with new ones every few years. About 3 years after planting, coffee produces the first flowers; it takes about 7 years to come into full bearing. It takes 7–9 months from flowering to maturity of the fruits.

As in non-seasonal climates coffee flowers throughout the year, fruits are harvested the year round. In countries with a distinct seasonal climate, well-defined cropping periods are found. After picking Arabica coffee, fruits are usually pulped, fermented to degrade the mucilage, washed and dried. Robusta fruits, which are often picked in various stages of ripeness, are dried directly. Subsequently the dried coffee is hulled to remove the parchment and remains of the silver skin (Fig. 1.6) and grated in coffee mills, bagged and marketed. The final stage of processing, including blending, roasting and packaging as whole 'beans' or ground coffee, takes place close to the consumer market.

Annual yields per hectare vary widely depending on cultivar, climate, soil fertility and age, from 400 kg up to 6000 kg of green 'beans'. In 2004, the total world production of green coffee 'beans' was almost 8 million t. At present, the major producers of Arabica coffee beans are Brazil and Colombia. Vietnam and Indonesia are the most important producers of Robusta coffee beans.

Tea

Tea – *Camellia sinensis;* Camellia family – *Camelliaceae*

Origin, history and spread

Camellia sinensis has its natural habitat in the lower montane forests from south-western China to north-eastern India. In China it has a long history of use, dating back about 4000 years. Tea has been used in many ceremonies; it is said that it kept Buddhist monks alert during long meditations. There are many references to tea from the time before Christ, as can be found in an old Chinese dictionary. Since ancient times, tea has been valued for its properties as a healthy and refreshing drink. Tea became China's national drink during the Tang Dynasty, AD 618–906; they called it 'ch'a' and 'tay', which is in the English language corrupted into 'tea'. The spread of the plant throughout China and Japan can be attributed to the travelling of Buddhist monks through this region. The Chinese author Lu Yu wrote the first book about tea in about AD 780. Tea cultivation in Japan started in the 9th century. Tea was already known to Arab traders around AD 850; they probably brought tea to Europe via Venetian traders in about 1560. However, it is the Portuguese and the Dutch who claim to have introduced tea and tea drinking into Europe in the 16th and 17th centuries. England entered the trade in the mid- to late 17th century. Tea reached North, Central and South America with European settlers in the 16th century. Tea from Japan and China was introduced into Java in 1690. Subsequently, tea spread into many tropical and subtropical countries. In the 19th century, many plantations were developed, but at first they were often not remunerative. That changed when promising wild tea types were discovered in Assam and Manipur.

Fig. 1.9. Tea: 1, flowering branch; 2, fruiting branch, 3, pluckable shoot (line drawing: PROSEA volume 16).

After 1836, these types were planted in commercial plantations; at first in hilly areas of north-eastern and southern India, next in former Ceylon (Sri Lanka) in the 1870s, and in Java in 1878. Tea was planted in Russia in 1846, although the first successful plantation in this region was developed in Georgia in 1895. From Kew Gardens in England, tea was brought to former Nyasaland (Malawi) in 1886; it was subsequently introduced into Kenya, Tanzania and Uganda in the 1920s and 1930s. In 2004, tea was grown in 45 countries.

Botany

Tea (Fig. 1.9) is an evergreen tree that can be up to 16 m tall in the wild. In cultivation it is usually pruned back to a shrub 0.5–1.5 m high and up to 1.5 m wide. The leaves are alternate, simple, lanceolate to obovate, 4–15 cm × 2–5 cm, leathery, serrate, acute or acuminate. The colour of the older leaves is dark green above and light green below, the lower surface of the leaves is slightly pubescent. The flowers are axillary or subterminal, single or in clusters of two to four. The flower is very fragrant, yellow-white or pinkish, 2–4 cm in diameter. It consists of five to seven sepals and five to seven obovate, concave petals; numerous yellow stamens; petals and outer stamens are united for a short distance at the base; the pistil has a superior three- to five-carpellate ovary, each carpel with four to six ovules. The fruit is a capsule, depressed globose, three-lobed, brownish-green, valvate, up to 2 cm in diameter, thick-walled and woody (Fig. 1.10). The capsule contains one or two subglobose seeds in each lobe. The seeds have a light brown testa, no endosperm but thick cotyledons; they are rich

Fig. 1.10. Tea: flower and flower buds (left) and unripe fruits (right) (photo: D.L. Schuiling).

in oil. The 1000-seed weight is about 450–500 g. Tea has a strong taproot with a dense mat of feeder roots that lack root hairs but have endotrophic mycorrhizae in the top layer of the soil. Some lateral roots grow 3–4 m deep for good anchorage.

Varieties, uses and constituents

Tea cultivars may be classified in two main groups.

1. China teas: slow-growing, multi-stemmed trees, with small, erect, comparatively narrow leaves; flowers borne singly; relatively resistant to cold; and producing a rather low yield. This variety yields some of the most popular teas.
2. Assam teas: quick-growing, single-stemmed, taller trees with large drooping leaves; flowers in clusters of two to four; adapted to tropical lowland conditions; these teas often have larger yields. They give a darker and stronger-tasting beverage. All Assam teas and most Ceylon teas are from this variety.

A large-leaved variety 'Makino' is grown mainly in Japan; characteristic is its bitter extract. Many hybrids between China and Assam types occur. Tea crops can be very heterogeneous due to cross-pollination.

C. sinensis is the plant whose leaves and leaf buds are primarily used to produce tea. For tea production, young light green leaves, usually the tip (bud) and the first two or three leaves beneath, are harvested (Fig. 1.11). The beverage is obtained by infusing the leaves in hot water; it has a stimulant effect due to caffeine. Caffeine content of fresh leaves is about 4%.

Four different tea types can be distinguished.

Fig. 1.11. New shoots ready to be plucked (photo: A.E. Hartemink).

1. Black tea: the leaves are withered, rolled or crushed, fermented, dried, sifted and graded; the processed leaves have a black colour; it is prepared from China and Assam tea.
2. Green tea: the leaves are steamed and dried unfermented. The processed leaves have a green colour; it is prepared from China tea.
3. White tea: the leaves have to be picked before they open fully, the opening leaves and the buds are still covered by soft white hairs; hence the name. Like green tea, the leaves are steamed and dried. The processed leaves have a green colour; it is prepared from China tea.
4. Oolong tea: the leaves are rolled, fermented and dried. While green and white teas are unfermented and black tea is 100% fermented, oolong tea is in between because it is semi-fermented. After processing, the leaves have a deep green colour; it is prepared from China tea.

All four types are harvested from the same species but processed in different ways to obtain different levels of oxidation. Black tea is commercially far the most important type. More than 78% of the present world tea production is consumed as black tea; the largest volume comes from the Assam variety. Several speciality teas are offered to consumers, based on origin ('Darjeeling'), blend ('English breakfast'), form ('pekoe' is cut, 'gunpowder' is rolled) and added flavour like orange, jasmine and many others.

Tea extract is also used for flavouring (alcoholic) beverages, dairy desserts, candies, confectionery and puddings. From the seeds of the tea plant, tea oil can be extracted, which is a sweetish salad and cooking oil. The characteristic flavour and aroma of tea as a beverage are due to the most important constituents, which are polyphenols, caffeine and essential oils. Leaf buds and the youngest

leaves have the highest caffeine and polyphenol content and produce the best-quality tea. Dried leaves and leaf buds contain approximately 30–35% polyphenols, 15% protein, 2.5–4.5% caffeine, 22% polysaccharides and carbohydrates, 4% amino acids (including theanine), 5% inorganics, and a few organic acids (mainly ascorbic) and volatile substances. Furthermore, it contains small amounts of vitamins A, B-complex and C.

In folk medicine tea is recommended for the treatment of numerous ailments, especially in China. For example it is regarded as antitoxic, diuretic, carminative, digestive, stimulant and stomachic; tea is reported to be effective in the treatment of bacterial dysentery, gastroenteritis, hepatitis, and many more. Recent studies have indicated that by drinking certain amounts of tea, the average blood cholesterol level may drop; it may cause lower systolic blood pressure level; it increases antioxidant activity; and it may reduce the risk of cardiovascular diseases.

Ecology and agronomy

C. sinensis thrives on a wide range of soils with the texture of sandy loam to clay. They should be well drained, having a good water-holding capacity, be about 2 m deep and with a pH of 4.5–5.6. An annual rainfall of 1700 mm or more is required. Rainfall should not fall below 50 mm per month. The species is cultivated in tropical and subtropical regions. It can be grown from the equator up to latitudes as high as the Black Sea coasts of Russia or northern Japan. It is grown from sea level up to 2300 m altitude. Generally, optimum temperatures for growth are between 18 and 30°C. Climatic conditions have a great influence on the quality of tea. In the tropics fast shoot growth in the lowlands is detrimental to the quality, while at higher altitudes of 1200–1800 m above sea level, high yields combined with excellent quality can be obtained. Hail can cause considerable damage to the leaves; night frost damages the leaves as well but does not kill the tea plant. China cultivars are more cold-tolerant than the Assam cultivars.

Tea is propagated both from seed and by cuttings. Seeds are usually picked from selected, free-growing trees, or from two or more selected clones, the latter yielding biclonal or polyclonal seed. Seed production has to be carried out in special isolated gardens. For germination the seeds are often placed in trays and covered with wet fabric; seeds may also be germinated in sand in beds or trays. After germination the seeds are transferred to shaded nursery beds. After 1.5–2.5 years the young plants can be transplanted to the field. For vegetative propagation, single-noded cuttings are made and placed in small polythene containers, with the leaf and bud just above soil level. The containers are subsequently placed in a polythene tunnel under shade; after 6–9 months the rooted cuttings can be transplanted to the field. Plant densities depend on climate and cultivar, but tea is often planted in rows, at densities of 11,000 to 14,000 bushes/ha. Planting in the row can be 60 cm apart and spacing between the rows 120 cm. Before planting, the soil should be thoroughly cultivated. After planting, suppression of weeds is essential, especially during the period of establishment. Particularly stoloniferous grasses can be very deleterious in Asia.

Sometimes tea is interplanted with green manure crops. Once the plants are established, deep cultivation for weed control has to be avoided, because it will damage the surface feeder roots. At most, a light scraping of the surface can be tolerated. Weed control can also be carried out chemically.

Tea requires regular fertilizer application to produce good yields. Foliar analysis provides information on the nutrient status of the tea bush. Application of fertilizer can also be based on soil analysis data and the nutrient removal of the crop. An annual tea crop of about 1000 kg of processed tea removes approximately 45 kg N, 3 kg P, 17 kg K, 6 kg Ca and 1.5 kg Mg.

In tea cultivation, a naturally small tree has to turn into a low, wide-spreading bush to maintain a convenient height for plucking. The top level of the bushes is called the 'plucking table'. To keep the bushes in good shape, pruning is required; pruning cycles depend on altitude and may vary from once every year up to every 5 years. If possible, pruning should be done during a dormant period. The first time the leaves can be plucked depends on the propagation method and the environment; it varies from 2 to 4 years after planting. Bushes are usually plucked every 7–10 days at lower elevations and every 14 days in colder climates (Fig. 1.12). The economic life of a tea bush is assumed to be 40–50 years; however, many 70–100-year-old bushes are still productive at present.

At harvest, terminal sprouts with two or three leaves are usually hand-plucked (machines for removing leaves have been developed, but until now they are not much used). Subsequently the leaves can be spread thinly on trays and placed in the sun for about 12 h or more, until the leaves are flaccid. As mentioned before, various techniques are used to produce different types of tea; the processes may include withering, rolling, fermentation, steaming, drying, sifting and grading. During these processes, the leaves may become broken up. After the processed tea is dried, the brittle leaves are usually stored in airtight tin boxes or cans and

Fig. 1.12. Harvesting tea leaves, Sumatra, Indonesia (photo: J.D. Ferwerda).

marketed. Ten kilograms of green leaves produce about 2.5 kg of dried tea. World average yield for China teas is about 900 kg of processed tea per hectare per year, ranging from 500 to 1600 kg. The yields of Assam teas range from 600 to 2100 kg/ha. In 2004, the total world production of processed tea was 3.3 million t. The major producers are China, India, Kenya and Sri Lanka.

Tobacco

Tobacco – *Nicotiana tabacum*; Nightshade family – *Solanaceae*

Origin, history and spread

All tobacco varieties belong to the genus *Nicotiana*. The genus contains about 65 species, most of them native to tropical America.

The growing of tobacco began in Central and South America by Indians, over 3000 years ago. For them it was a sacred plant, used for healing practices, used to communicate with the spirits and also used for pleasure. It played a part in all kind of rituals and tribal ceremonies. One way to use tobacco was rolling many leaves to obtain a very large cigar, which they called 'tabaco'. However, tobacco was used in various ways: smoking dried leaves, drinking tobacco juice, chewing the leaves and sniffing tobacco powder. Tobacco played such an important part in everyday life that it was sometimes mythicized: Indians of the Huron tribe told that a long time ago the Great Spirit sent a woman to the earth to help the people. She walked over the world and touched the soil. When she touched the soil with her right hand, there grew potatoes; when she touched the soil with her left hand, there grew corn; and on all places where she sat down to rest, there grew tobacco afterwards.

Tobacco was introduced into Spain and Portugal in the mid-16th century, where it was used as an ornamental plant and a medicine at first, later as a stimulant. In 1566 Jean Nicot de Villemain, France's ambassador to Portugal, introduced tobacco to the French Court. It spread to other European countries and then to Asia and Africa, where its use became general in the 17th century. In North America the first tobacco was planted in Virginia in 1612. In the mid-17th century Linnaeus named the plant genus *Nicotiana*, in homage to Jean Nicot. Linnaeus described two species: *Nicotiana tabacum* and *Nicotiana rustica*. The first tobacco cultivated in Europe and North America was *N. rustica*. Later it was replaced by *N. tabacum*. Both species are believed to be of hybrid origin, because they are not known in the wild. They originate from Peru and Bolivia. The main source of commercial tobacco now is *N. tabacum* (about 90% of the world production). On a much smaller scale, *N. rustica* is grown for use in Oriental tobacco. Today tobacco is grown in 120 countries.

Botany

N. tabacum (Fig. 1.13) is an herbaceous annual growing to 2–3 m high, covered with short, sticky hairs. The erect stem is thick, unbranched, with a taproot.

Fig. 1.13. Tobacco: 1, leaf; 2, inflorescence; 3, flower; 4, corolla limb; 5, opened corolla tube showing stamens and pistil; 6, calyx with fruit (line drawing: PROSEA volume 16).

The leaves are more or less stem-clasping, thin, simple, variable in size, up to 30–40 cm long and alternate. The shape is ovate to oblong-lanceolate and the surface is dull. The number of leaves per plant is about 30. The colour of the flowers is usually pink but may be paler or redder. They are borne in terminal panicled racemes with up to 150 flowers per inflorescence. The flowers are about 5 cm long and have a tubular and five-cleft calyx, and a funnel-shaped and five-lobed corolla. Furthermore, there are five stamens, which are attached to the corolla tube and almost as long. The stigma is borne on the end of a long style of about the same length as the stamens. The fruit is a two-celled, many-seeded capsule, 1.5–2 cm long, the greater part enclosed by the calyx (Fig. 1.13). The number of seeds varies from 2000 to 5000 per capsule. The seeds are light to dark brown and very small; 1 g may contain 12,000 seeds.

N. rustica (Fig. 1.14) resembles *N. tabacum* but there are some differences: the plant is smaller (up to 1.8 m); the corolla is shorter and coloured yellow to green; the leaves are usually petiolate, ovate or cordate in shape with a dark, shiny surface.

Cultivars, uses and constituents

Growers and breeders have developed a wide range of morphologically different types and cultivars, from the small-leaved aromatic tobaccos to the large, broad-leaved cigar tobaccos. The final product determines the needed type or cultivar.

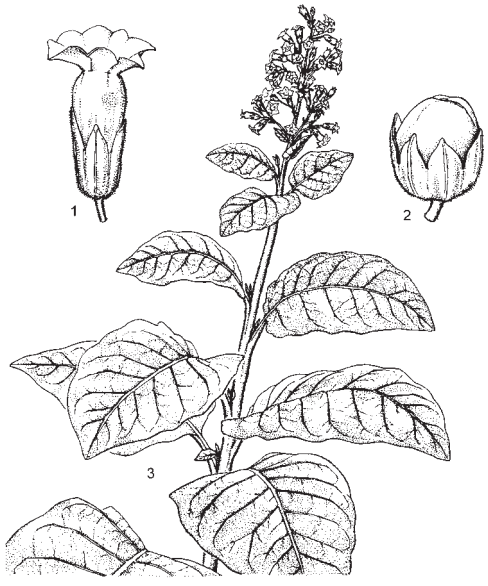

Fig. 1.14. Nicotine tobacco: 1, flower; 2, calyx with fruit; 3, upper part of flowering plant.

Besides taste, the most important reason for using tobacco is the stimulating and light narcotic effects of the alkaloid nicotine. Therefore the leaves are harvested and dried (cured), rolled into cigars or shredded for use in cigarettes and pipes, or processed for chewing or snuff. The final use of tobacco leaves is determined by several factors including cultivar, climate, soil and method of curing. The leaves are cured, fermented and aged to develop aroma. The most important cure methods are air-curing, sun-curing, fire-curing and flue-curing.

1. In air-curing the leaves are hung in well-ventilated barns, or in an open framework in which leaves are protected from wind and sun. It takes 1–2 months to dry. South and Central America are important producers of air-cured tobacco. This group has low sugar content but varies in nicotine content. The colour of the dried leaves is reddish-brown because the tannins present in the leaves oxidize. This tobacco is used mainly for cigars.
2. In fire-curing the leaves are dried in smoke and hot air. It takes about 4 weeks to dry. Fire-cured tobacco has a low sugar and high nicotine content. The colour of the dried leaves is dark brown. Fire-cured tobacco is used mostly for pipe, snuff and chewing tobacco.
3. In flue-curing the leaves are dried by radiant heat from flues connected to an oven, taking 1 week to dry. Flue-cured tobacco has high sugar content and a medium to high nicotine content. The colour of the dried leaves is yellow, orange or mahogany. Most of the flue-cured tobacco is used for cigarettes. Worldwide the most extensive variety, Virginia, is flue-cured.
4. Sun-curing is the drying of uncovered leaves in the sun. The best known are the Oriental tobaccos from Greece, Turkey and other Mediterranean countries. They have very characteristic aromas, a low sugar and nicotine content, and are used in cigarettes.

Fig. 1.15. Close-up of tobacco field, East Java, Indonesia (photo: D.L. Schuiling).

Fresh tobacco leaves (Fig. 1.15) contain 85–90% water, which falls to 12–15% during the curing. On a dry weight basis flue-cured tobaccos contain sugars 18–20%, starch 5–8% and proteins 2%. Air-cured tobaccos contain only a few per cent of sugars but 3–15% proteins. The nicotine content of cured leaves of *N. tabacum* varies from 1 to 4%.

After curing the leaves are graded, bunched and stacked in piles or closed containers for active fermentation and ageing. Most commercial tobaccos are blends of several types. Flavourings such as sugars, fruit juices and spices are often added.

Because of the high nicotine content of *N. rustica* (4–9.5%), this species is also grown for nicotine extraction to produce natural insecticides.

A number of *Nicotiana* species are grown as ornamentals, e.g. *Nicotiana alata*, *Nicotiana langsdorffii*, *Nicotiana sylvestris*. Height, width and shape of the leaves are variable. The trumpet-shaped flowers can be pink, red, green or white, often quite fragrant (Fig. 1.16).

Ecology and agronomy

Tobacco is grown under a wide range of climatic conditions (60°N–40°S), but the crop needs a minimum of 120 frost-free days. Tobacco grows on a variety

Fig. 1.16. Inflorescences of tobacco (left) and nicotine tobacco (right) (photos: J. van Zee).

of soils, although preferably on light to medium loams, well-drained and slightly acidic, pH 5–6 (Fig. 1.17).

As tobacco has very small seeds, it is not possible to sow directly in the field, unless the seeds are pelleted. Seedlings are raised in glasshouses and then transplanted to the field. Ten grams of seed is needed for 1 ha. Seeds of most cultivars require light for germination. Young seedlings are planted out by hand or by a mechanical transplanter. Spacing between seedlings and rows varies with the kind of tobacco and with the location. The average plant density is 18,000–25,000/ha for most tobacco types.

The crop needs 400 mm of water during the growing period. Fertilizer rates are 20–60 kg N, 10–20 kg P and 25–60 kg K per hectare. N uptake of tobacco plants must not be too high due to risk of high N content of the leaves, which may cause a decline in the quality of the leaves for the production of tobacco.

Tobacco can be topped or the flower buds can be picked off, as this appears to increase the size and thickness of the leaves. The negative effect is the development of dormant axillary buds into lateral branches (suckers). The suckers have to be removed. To achieve large and tender leaves, shadow-textile is sometimes placed above the growing crop.

Tobacco is susceptible to numerous fungal, bacterial and viral diseases and can be attacked by several species of insects.

The first and lowest leaves are mature about 2 months after transplanting. When the leaf is fully ripe, which means when the colour is yellowish-green and the tip yellow, harvesting can begin. Tobacco is often stalk-cut by machine or harvested by hand, leaf by leaf. The leaves are tied together in pairs on curing

Fig. 1.17. Tobacco field, Pinar del Rio, Cuba (photo: T. Andersson).

sticks or strings. World average yield of cured tobacco leaves is 1.5 t/ha. The world production in 2005 was 6.6 million t of dried tobacco leaves. Asia accounts for 64% with China as main producer (41%), the Americas including the Caribbean for 19%, Europe 8% and Africa 5%.