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# GROWTH AND PRODUCTION OF RUBBER

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**Keywords** : Agro-chemicals, estate, Hevea, industrial plantations, land clearing, land management, latex, rubber.

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## Summary

Rubber is a tropical tree crop which is mainly grown for the industrial production of latex. Like oil palm it requires a high and year-round rainfall with little or no dry season and stable high temperatures; soils should not be particularly rich, but must be deep and well drained. Both crops are often grown in the same ecological areas, and in many cases oil mills and rubber treatment plants form part of one and the same industrial complex.

Rubber trees grow mainly in tropical lowlands below 400m altitude, originally covered by a dense tropical rainforest. Dry spells or temperatures below 18° C do not affect vegetative growth but reduce latex yield. Fertilizer demands for the tree are only important in the vegetative development stage (first 6 years) when the biomass is built up. Once the tree is mature and latex tapping has

started the mineral fertilizer supply for compensating the nutrients exported by the latex is much smaller.

Rubber is the major industrial product derived from the latex from a number of trees belonging to the genus *Hevea*. The bark of these trees contains a network of interconnected vessels through which the latex flows when opened. Latex is a suspension of rubber particles which have to be coagulated to obtain the rubber. About 90% of the total world production of natural rubber is obtained from *H. brasiliensis*. Currently, natural rubber on the world market is competed by synthetic rubber, which is derived from oil products.

## 1. Introduction

Rubber (*Hevea brasiliensis*) is a fast-growing upright tropical tree crop which is mainly cultivated for its production of latex, a milky plant liquid, which serves as a basis for various rubber products. It is a typical plantation crop, which means that it should be grown and harvested over large uniform areas (3,000 to 5,000ha) around a central treatment unit to allow for a relatively rapid industrial handling after harvesting.

Rubber has quite similar growth requirements as oil palm, and both crops are therefore cultivated in the same geographical areas. The trees require deep soils, relatively stable high temperatures and continuous moisture throughout the year; soil fertility is less important than physical soil properties. Dry periods of more than 2-3 months do not specifically damage vegetative growth, but affect seriously the production and quality of the latex. Palm oil mills and rubber treatment plants are often associated in one single industrial complex.

Because both industrial crops need the clearance of large areas they often require the expropriation of land and the cutting of extensive forest areas. Hence, the development of such plantations is often a source of land tenure conflicts and problems of local land ownership, viz. ecological problems and biodiversity loss.

## 2. Origin and Distribution

The genus *Hevea* is native to South America, where it grows wild in the Amazon and Orinoco valleys. Before the discovery of the New World, native Indians used the latex of various plants for making balls, bottles, crude footwear and waterproofing fabric. Only one of these plants, *H. brasiliensis* (HBK) Muell Arg, later developed as the major latex-producing crop.

Columbus was the first to report (1495) about latex, but it was not before 1775 that the rubber tree was properly described by the French explorer Fusée Aublet. Almost by the same period Priestly discovered that latex could rub out pencil marks, and this gave the product its name as rubber. In 1823 MacIntosh made waterproof cloths by coating fabric with rubber dissolved in naphtha. The use of waterproof clothing in the American Civil War brought about the first rubber boom, followed by a second one in 1839 after Goodyear and Hancock had discovered the principle of vulcanization; this is the process whereby rubber is heated with sulfur and retains its physical properties once processed into a useful shape. The most successful application of latex rubber was achieved in the 1880s when rubber was found to be the basic material for pneumatic tyres for motor cars.

The real success story of rubber as a modern commodity started after it could be industrially cultivated. This did not happen before Wickham (later Sir Henry) collected some 70,000 seeds from the Tapajoz valley (Amazon, Brazil) and brought them, first in 1876 to Kew Gardens (London) and later to Ceylon (1876) and Singapore (1877). Research in the Singapore Botanic Gardens by H. Ridley identified *H. brasiliensis* as being superior to all other rubber-producing plants. At this

institute much of the technology was also developed for the excision method of tapping (see below), the opening up of the same cut which increased the flow of latex (wound response), the best time to tap, and the regeneration of the bark, which could then be re-tapped. Later, granulated and various rubber grades were identified. To date, more than 99% of the world production of natural rubber comes from *H. brasiliensis*; the remainder is extracted from guayule (*Parthenum argentatum*), a rubber containing shrub.

The first rubber plantations in Malaysia were established as early as 1890. *Hevea* was introduced in Africa early in the 20<sup>th</sup> century: in Uganda and Nigeria (1903), Congo (1904), and Liberia (1924, by the Firestone Tyre and Rubber Company). Today, most latex production is concentrated in industrial estates in tropical Africa and the Far East.

The world rubber market over the past 100 years has been extremely volatile. A first major production boom in the Far East was stopped by the First World War, cutting of most of the consumer markets in Europe and North America, and leading to a drastic price cut. The latter resulted in an intensified search for more rational production methods, development of budding techniques, selection of better clones, and the introduction of cover crops to reduce weeding and fertilizer costs. The Second World War created another problem in the sense that most Asian plantations fell into the hands of the Japanese and were cut a second time from their major consumer markets. This resulted in the discovery of synthetic rubber from 1910 onwards by the Russian chemist Sergei Lebedev and the creation of a new synthetic rubber industry, mainly in the United States, which started to compete natural rubber on the world markets.

*Hevea* is nowadays cultivated as far north as 25° North (Yunnan Highlands, China) and as far south as 21° South in Brazil. The main production zone, worldwide, is however concentrated between 15° N and S. For South East Asia and the South Pacific this includes Malaysia, Indonesia, Thailand, Sri Lanka, South India, Cambodia, Vietnam, The Philippines, Papua-New Guinea and Southern China. There are important plantations also in Central and West Africa (Congo, Cameroon, Ivory Coast, Liberia), while rubber cultivation in tropical America is concentrated over a small area between 10° N and S

### 3. Botany

#### 3.1 Cultivars and Classification

Rubber belongs to the family of Euphorbiaceae, a large family with about 280 genera and 8,000 spp. The genus *Hevea* exhibits much morphological variability, with nine species now being recognized, ranging from large forest trees to little more than shrubs. All of them contain latex in their parts. Other *Hevea spp* are tapped in a wild state, but are of little economic value. Some of them may however be important for breeding :

- *H. benthamiana*: occurs only north of the Amazon river in the north-western part of Amazon and Upper Orinoco basins; it grows in low alluvial areas and bogs and, thus, supports hydromorphic soils; it has a pure white latex which is lower in yield than *H. brasiliensis*;
- *H. camporum*: native of open savannas in the headwaters of the Madeira River, Brazil;
- *H. guianensis* and its variety *latea*: 30m high or more; it prefers well-drained upland soils; its yellowish latex yields generally inferior rubber;
- *H. microphylla*: endemic in uppermost Rio Negro basin in Brazil, Colombia and Venezuela; up to 20m high; grows in low-lying, often permanently flooded land; its white watery latex almost completely lacks rubber;

- *H. nitida*: occurs throughout most of the Amazon valley and upper Orinoco; the tree is medium-sized and usually grows on sandy forest soils; the thin white latex acts as an anti-coagulant with that of other spp;
- *H. pauciflora*: occurs in Rio Negro and the Upper Orinoco basins and in Guyana; the medium-sized tree grows on rocky hillsides and high well-drained river banks; its white latex has a low rubber and high resin content;
- *H. rigidifolia*: endemic to the uppermost Rio Negro basin of Brazil, Colombia and Venezuela; the 20-meter high tree grows on high, well-drained soils; its cream-colored latex is poor in rubber and high in resin content;
- *H. spruceana*: abundant in lower Amazon basin; it grows on low and flooded river banks; its watery latex is almost devoid of rubber.

### 3.2 Structure

*Hevea brasiliensis* (HBK) Muell Arg is a quick-growing tree, rarely exceeding 25m in height in plantations, where the plant density is optimal for light interception; wild trees might be up to 40m high in search for sunlight above the dense tree canopy. The tree has a well-developed tap-root, 2-5m long after 3 years, with laterals several meters long. The lateral roots emerge from the tap-root below the collar. They can reach up to 10m and can make a dense network of feeder roots and root hairs in the upper soil layers. Some 30 to 60% of feeder roots are found in the top 10cm of the soil. Figure 1 depicts the various structural elements of the tree.

Figure 1. *Hevea brasiliensis* or Para rubber (Legend: A: shoot with dehiscing fruit; B inflorescence; C: male flower cut open; D: female flower in longitudinal section; E1-2: fruits; F: seed).(Courtesy Purseglove, 1977)

The **trunk** of the tree tapers from the base and is conical or cylindrical in shape and shows a periodicity of growth. During the resting stage whorls of scale leaves occur round the terminal bud. A fully grown leaf has a diameter of 15-20cm. Young leaves are dark red in color, while other leaves are green on top and grayish-green underneath. In trees which are old enough, leaves shed at the beginning of the dry season, terminal buds of branches grow rapidly and trees are temporarily bare of leaves, a condition known as “wintering”. New leaves are then produced at the proximal end and inflorescences in the axil of scale leaves and lower foliage leaves. This so-called wintering is usually associated with dry weather conditions. It is more pronounced as the seasons themselves differentiate. Beyond 4° latitude north and south wintering is short but sharp, whereas at the Equator it becomes apparent only when the trees enter production.

The **crown** of the rubber tree is liable to be damaged by wind, causing the trunk to snap. Hence, the need to select clones with a balanced tree architecture, i.e. limited growth of the primary axis, with numerous similar but short secondary branches evenly distributed round the tree. Windbreaks consisting of *Tectona* and/or *Eucalyptus* trees might limit the damage.

**Flowers** are borne in many-flowered, axillary, shortly pubescent panicles on the basal parts of the new flush. Flowers are small, scented, unisexual and shortly-stalked, with larger bell-shaped female flowers at the terminal ends of main and lateral branches, and more numerous smaller male flowers, with 60-80 males to each female flower. Flowering takes place over a period of about two weeks with some male flowers opening first, lasting for one day and then dropping, followed by female flowers open for 3-5 days; the remainder of male flowers then open.

**Fruits and seeds.** Only a small proportion of female flowers set fruit and of these 30-50% fall off after a month, and more fall off later. The mature fruit is a large, compressed, 3-lobbed capsule, 3-

5cm in diameter, with 3 oil-containing seeds. The capsule bursts open at the end of the rainy season with a characteristic loud bang, similar to a rifle shot. The seeds are then collected for sowing in the nursery.

A *Hevea* seed is oval, 1-2cm long, and weights between 3 and 6g. It has a hard, shiny coat which is brown or grayish-brown in color. Seeds are viable for a short time only, and must therefore be planted as soon as possible after harvesting. Viable seeds germinate in 3-25 days. Germination is hypogeal.

The **bark** is the most important part of the tree – and even of the plantation as a whole – because it contains the tissues that produce the latex. Figure 2 shows a cross-section of the trunk of an adult rubber tree. It consists of a pith, wood and a cortex, which is separated from the wood by the cambium (regenerative tissue). In the cortex, there are 3 separate concentric layers: the outer corky layer (periderm), an underlying parenchyma with a large numbers of stone cells, and finally the phloem with the latex vessels. The thickness of the bark and the proportion of tissue vary with different clones, and with the age of tree.

Figure 2. Cross section of an adult rubber tree showing the composition of the bark and the position of the latex vessels in the soft bark tissue (Courtesy L. Boedt, 2001)

**Latex vessels** are found in the tree's soft bark. They are modified sieve tubes (cells formed by the cambium and coalescing when the dividing cell walls disintegrate) running anti-clockwise in concentric cylinders at an angle of approximately 30° to the vertical axis of the stem (which is why tapping is done invariably from top left to bottom right in order to cut the vessels at a right angle). Vessels are laterally interconnected with each ring, but connections are disrupted as the trunk expands. The number of vessels per ring and the number of rings vary with age and thickness of the bark and with the clone.

When tapping, part of the bark is scraped, whereby the latex vessels are cut causing the latex to flow. Tapping is done with precision using special knives to prevent damaging the underlying cambium. In renewed bark the number of functional vessels is increased.

**Fresh latex** consists of a colloidal suspension of rubber particles in an aqueous serum. The content of rubber hydrocarbon, with formula  $(C_5H_8)_n$ , varies from 25 to 40 %, with an average of about 30 %. It is manufactured in the tree from carbohydrates, and it has two major functions: making the plant less attractive to pests because of the taste latex gives to parts of the tree, and protecting the plant by sealing of the wounds so that no aggressors can penetrate the tree. Latex consists of four main fractions (Delabarre and Serrier, 2000):

- Rubber particles (25-40% of total latex volume), variable in shape, but usually pear-shaped or spherical, and about 6 nm to 5 micron in size;
- Lutoids (10-20%), 0.5 nm to 3 micron in size, having an impact on the stability and flow of the latex;
- Frey-Wyssling particles (5%) which play probably a role in the coagulation and oxidation-reduction processes; and
- Other elements like proteins, resins, sugars, glycosides, tannins, alkaloids, mineral salts, and secondary metabolites.

**Vegetation cycle** – *Hevea* has an annual vegetative cycle, with a leaf fall or “wintering” in the dry season (see above). At this moment also the latex flow is less prominent. The tree has a tap-root which, under favorable growth conditions, penetrates 4 to 5m deep in the soil.

### 3.3 Pollination and Propagation

**Pollination** - *Hevea* is entomophilous. Pollination is mainly by midges, which are only active around sunrise and sunset, and thrips operating throughout the full day. As these pollinators do not fly far and as wild *Hevea* in Brazil is widely scattered, it was likely that under natural conditions self-pollination might have taken place, and that multiplication of trees was by seeds. CIRAD/IRCA (*Centre de Coopération Internationale en Recherches Agronomiques pour le Développement/ Institut de Recherches pour le Caoutchouc*) in Ivory Coast, and RRIM (*Rubber Research Institute*) in Malaysia are world famous centers for the research and development of new high-grade clones.

**Propagation from Seeds** - Seeds may be planted at stake in the field or in nurseries. The advantage of using nurseries is that the planting material is more homogeneous, because weak or poorly developed plants are regularly eliminated from the nursery. For nursery planting, seeds are first germinated in shaded beds of compacted friable soil, shaded with sacking, and watered daily. Germination is more or less complete in 2-3 weeks, and germinated seeds are transplanted into shaded nurseries once their tap-root measures 1-2cm in length and their stem begins to develop.

Nurseries have to be established in flat areas and close to a water source, because young plants have to be irrigated daily. For a plantation of 100ha about 1ha of nursery is needed. The soil has to be deep-plowed, carefully cleared from remaining roots, and be kept free of weeds. When there is a risk of damage by rodents, the nursery should be enclosed. During the rainy season nursery plants are regularly treated with fungicides as a preventive measure to combat leaf diseases.

Young plants in the nursery can be grown as seedlings or in polythene bags. For seedling rubber the germinated seeds are planted in the nursery at 30 x 30cm, giving approximately 100,000 plants per ha, of which 60,000 – 70,000 should reach the standard size for pulling at 10-15 months. The entire plant is dug or pulled out of the ground, tied into bundles, transported to the field and planted. It is also possible to plant the germinated seeds in baskets or in perforated polythene bags (Figure 3).

Figure 3. *Hevea* plant budded with improved clones in a nursery.  
Prior to transplantation in the field, the rootstocks are cut obliquely above the budding point to stimulate the growth of the clone (Courtesy L. Boedt, 2001).

**Propagation from Budding** – An alternative widely applied propagation method is by budding, which gives higher yields. Budwood nurseries are established by planting germinated seeds in rows 1m apart with 2 seeds 15cm apart. The stronger seedling of the two is budded after one year with the desired clone, or the smaller seedling if the larger one fails. Such nurseries are usually maintained for about 7 years during which time 5 crops of budwood are taken.

Seedling stocks planted at stake in the field may be green budded at 5-6 months, but this should not be done during or when dry weather is expected. Brown budding is done at stake on plants of about one year old. For field budding two or more seeds are planted at stake; if more than two develop these are selectively thinned to two. The most vigorous seedling is budded and, if this fails, the second seedling is then available.

### 4. Ecology and Growing Conditions

Most natural rubber is grown between 15°N and 10°S where the climax vegetation is lowland tropical forest and where the climate is permanently hot and humid. *Hevea* has quite similar growth conditions as oil palm. It is a low altitude crop (maximum 700-800m at the equator, less high away from the equator). Sloping areas are less suited to rubber growth because of erosion risk and the difficult, viz. tiresome access for tappers and estate maintenance.

## 4.1 Climate Requirements

Ideal climatic growth conditions include high and rather stable mean temperatures, a well distributed high annual rainfall, and a relative air humidity between 60 and 80%. Solar radiation should be between 1,500 and 1,800 hours per year.

Optimal temperatures are between 24 and 26° C. Air temperature has a direct effect on the flow of latex during tapping, especially at the start of a dry season. Rubber trees can, however, cope with long periods of temperature below 15° C without much damage, at least when trees are young. Otherwise, such low temperatures might result in stunted growth and lower latex production in the long term. *Hevea* can even tolerate sudden nocturnal falls and even light frost, as is the case in Sao Paulo State, Brazil, and Southern China.

Annual rainfall is best in the range between 1,800 and 2,500mm. It should be continuous throughout the year except for a 2-3 months low-rainfall season followed by a substantial re-foliation. When rainfall exceeds 2,500mm leaf diseases develop easily (mainly fungal infections), and tapping may be disrupted because the rain dilutes the latex, causing it to spill on the ground. A 2-3 months relatively dry spell may be beneficial and may promote a substantial re-foliation. Trees can survive dry periods up to 5-6 months as long as there is water in the soil; plantations in such areas should therefore be located on soils with good water-holding capacity.

Rainfall over long periods during daytime holds up tapping. Even in the time between the tapping cut and the latex collection, serious losses may occur as cups may partly fill with rainwater, or latex may overflow the edge of the cups. The ideal rainfall pattern starts in the late afternoon and stops just before tapping the next morning.

*Hevea* is quite sensitive to wind. Strong winds may uproot trees or break stems. Wind damage is particularly dangerous in the first 10 years of establishment, or in poorly drained soils with a shallow groundwater table. No rubber plantations exist therefore in cyclone-prone areas like in part of The Philippines or in Madagascar.

## 4.2 Soil Requirements

Although the crop tolerates a wide range of soils, it grows best on deep (minimum 2m), well-drained and well-aerated, permeable soils of loamy or sandy clay texture (clay content > 20%). Too sandy soils are too poor in nutrients and have a low water-holding capacity. The performance in terms of latex production improves as the clay content in the top soil increases from sandy clay loam to sandy clay, and from sandy clay to clay in the subsoil. Shallow, poorly drained or peaty soils should be avoided. The crop can stand short periods of water logging. Coarse fragments in the soil reduce water retention and hamper root penetration.

Rubber plantations may be established on slight slopes, provided surface erosion and runoff is minimal. In sloping land tapping and latex collection is more difficult. On slopes above 5% contour planting is recommended; slopes above 25% should not be planted. Physical soil properties are more important than chemical composition

*Hevea* shows the best growth in fertile soils, but the tree can also stand poorer soils, except for the first 2-3 years of growth where a NPK growth stimulator is required. The optimal soil pH is between 4.5 and 6.0; higher pH values are tolerated, but lime is deleterious as it results in early latex coagulation on the excised bark and a reduction of the time of latex flow.



Nitrogen is generally supplied in sufficient amounts by the leguminous cover crop (as much as 200-300 kg N/ha/yr) or by the mineralization of the organic matter in the soil. The marginal level of P in the soil is estimated at 11mg/kg soil; for exchangeable cations (K, Mg and Ca) it is 0.30 cmol(+)/kg soil.

The total (cumulative) fertilizer application for immature rubber over the first 6 years from planting is around 200-250kg N/ha, 250-260kg P<sub>2</sub>O<sub>5</sub>/ha, 130-170kg K<sub>2</sub>O/ha and 20-50kg MgO/ha, depending on soil type and cover crop. Fertilizer recommendations for mature rubber (year 7 to 25) are estimated (IFA, 1992) at: 15-25kg N/ha/year, 20kg P<sub>2</sub>O<sub>5</sub>/ha/year, 60-150kg K<sub>2</sub>O and 10kg MgO/ha/year.

## 5 Land and Crop Husbandry

### 5.1 Planting and Land Management

**Planting area** – Latex should by preference be processed on the production site. Taking into consideration the economy of scale, a *Hevea* plantation should require an estate of minimum 3,000 to 5,000ha, with all-weather access roads for the transport of the latex. Smallholders' groves vary in size from 0.5ha to more than 10ha and their production generally adds in optimizing the capacity of the factory.

**Surface clearance** – If rubber is planted in areas of primary forest, all commercial timber is usually extracted beforehand, the remainder of the trees are felled, and the stumps are removed along the lines or contours of the field. Any vegetation is burned at the end of the dry season. To prevent root rot, caused by *Fomes spp.*, it is good to leave the cleared land fallow for at least a year or, alternatively to sow a creeping legume, usually *Pueraria phaseolus* or *P. tribola*. Besides protecting the land against erosion and enriching the soil in organic material, these cover crops have also a beneficial effect against pests and diseases.

Mechanical clearing of the forest is possible on big estates. The rows are cleared of obstacles such as fallen trees, and the soil is ripped to a depth of at least 80cm. Small farmers who can not afford heavy investments open for each tree a planting hole of at least 80cm deep.

In older estates all plant debris were burnt, followed by clean weeding, resulting sometimes in severe leaching, loss of soil structure, and soil erosion. This is still the most common way of land clearing in smallholders plantations, but in industrial plantations burning is no more accepted for ecological reasons (*see also: Growth and Production of Oil Palm*). Nowadays, it is common to fell the trees with a minimum disturbance of the soil and accumulate the trunks on the borders of the plot for composting while the area is rapidly covered by a (leguminous) cover crop. In replanting former rubber land, old trees may also be removed mechanically or be poisoned and, if cut down, stump surfaces are creosoted. All remains of roots have, in any case, to be removed from the soil. The economic life of a plantation is 25-30 years.

**Plant density** – Usually, the inter-row space in industrial plantations is 8m, with a spacing of 2.5m in the row. Hence, the number of trees is 450-550/ha. Other planting densities are possible and depend, among other things, on soil properties and competition for water and nutrients. High planting densities give high yields per hectare, but trees take often longer to reach a tappable size and give lower yields per tree and tapper in the beginning. Optimum density must be a compromise between yield per tree and yield per tapper (Figure 4).

Figure 4. General view of a standard rubber plantation, still with a dense cover crop.

Quite often, final tapping stands end up at 250-300 trees/ha as a result of thinning from original plantings of 375-450 buddings per hectare or 500-600 seedlings per hectare according to the degree of nursery selection. Half the thinning is done between year 3 and the beginning of tapping (year 6) on the basis of girth, and the remainder during the first three years of tapping on the basis of yield. The wider spacing between rows increases the susceptibility to wind damage, but increases the soil volume that can be explored by the tree in search of water and nutrients. Square or rectangular planting can not be done on steep slopes without the establishment of contour terraces.

**Planting** – Planting takes place in a hole in the soil, 0.5 by 0.5m in size and 50cm to 1m deep. Plants from a polybag nursery have soil around the roots and are less sensitive to drought stress. Plants that are transported bare-rooted can become rapidly dehydrated and need extra care at planting. Planting is best carried out at the beginning of the rainy season when the soil is sufficiently moist. Seedlings in polybags can, however, be planted later in the season.

An alternative method of planting is to sow the seeds directly in the field. All routine operations (maintenance, grafting, selection) have then to be performed outside the nursery, which involves extra costs. However, a clear advantage of this procedure is that the root system is much better developed.

**Intercropping and cover crops** - Most smallholdings apply an intercropping system with food crops to overcome the lack of income in the first years of establishment. It is recommended that annual crops should not be planted nearer the rubber tree than 1.2m (2m for bananas), and that cultivation should cease after 3-5 years when the rubber trees have almost reached full vegetative development. Herbicidal weed control is extensively practiced, particularly against grasses, especially *Imperata cylindrica*, which has a very deleterious effect upon rubber, and also provides a fire hazard.

In industrial plantations the inter-row space is rapidly planted, as is also the case for oil palm, with a cover crop (Figure 4). A good cover crop should have the following characteristics (*see also Conservation Agriculture*) :

- be perennial and easily multiplied and established, preferably by seed;
- have a rapid and vigorous growth to cover the soil and suppress weeds;
- not be competitive in water and nutrients with the rubber itself;
- not require frequent control for scrambling over or shading the trees;
- tolerate pruning or slashing if required and not die off when cut back;
- be able to establish itself on poor soil;
- have abundant leaves and provide rich litter which rots rapidly;
- fix nitrogen and provide this nutrient for the rubber;
- grow well in the early stages in full sunlight, but be shade-tolerant and persist when the tree canopy closes over;
- be resistant to drought;
- be resistant to pests and diseases, particularly those which might attack the rubber;
- not form products which are toxic to the rubber; and
- be easily eradicated when required.

The most currently used cover crops in rubber plantations are: *Calopogonium mucunoides* (grows quickly, gives good early cover in sun, lasts 18 months), *Centrosema pubescens* (slow early growth but persists under shade) and *Pueraria phaseoloides* (very vigorous when well established with little overhead shade).

**Other management aspects** – Rubber plantations are labor intensive and need a lot of skilled manpower, either to control the nurseries, do the weeding in the field, run the production plant and tap the latex. Careful tapping is a specialized job and has to be trained (Figure 5); tapping performances are favored through a bonus system. In establishing a new rubber estate the availability and schooling of a specialized labor force is a critical factor, and a training program on how to efficiently tap the latex is necessary.

Figure 5. Careful rubber tapping is a specialized job and needs training.

When starting up a new rubber estate in areas with a low population density, provision must be made for the necessary social infrastructure including schools, water and electricity supply, and medical care. In Malaysia the cost of labor and the availability of workers has in first instance caused a shift from daily tapping to systems in which tapping is less frequent (for example only 3 or 4 tapping rounds per fortnight) but with a higher yield of latex per session. In recent years a number of former rubber estates in Malaysia and Indonesia have shifted to oil palm estates due to production costs, shortage of labor and increasing personnel costs.

## 5.2 Plantation Maintenance

It usually takes 5-6 years before *Hevea* can be tapped for the first time. During this period a careful maintenance of the young crop is needed to ensure a good vegetative development. This maintenance includes in particular: pruning and removal of weak or diseased trees, fire protection, weed control, maintenance of the nutrient status, and control of pests and diseases. In the crop's early years most of these operations must be carried out by hand. From the third year onwards, the use of herbicides can be envisaged, and the inter-row maintenance can partly be done by mechanical means.

**Pruning** and elimination of weak trees is mainly operated at the nursery level, and to a lesser extent in the first years after field planting. Plants that fail to take root in the first two years in the field must be replaced at the beginning of the next rainy season. Suckers that grow from the rootstock must be removed as well, and it is essential that this operation starts as soon as plants start to take their final positions in order to ensure that the trunk is straight and smooth, and that branching begins high enough not to interfere with tapping afterwards.

**Weeding** is particularly important in the first years of planting when inter-rows receive still high amounts of sunshine. After a few years the canopy closes and weeds are less active. Weed control is expensive in terms of labor, and manual weeding is therefore only applied in smallholders groves. In larger plantations it is replaced by agrochemicals. There are of three main types of herbicides: contact herbicides (ex. Diuron, Paraquat), translocated herbicides (ex. 2,4 D-amine, Dalapon, Glyphosat), and soil-acting herbicides (ex. Atrazin, which is mainly used in nurseries). For environmental reasons the use of ecotoxic products is progressively abandoned.

**Maintenance of the soil nutrient balance** - Rubber responds seldom to heavy fertilizer applications, except probably in its early vegetative stage. During the early unproductive phase (years 1 to 5), most nutrients taken up by the tree are immobilized in the vegetative matter and the development of the tree biomass. In this period fertilizers are applied directly around the trunk: on average 5 times in the first year after planting, 4 times in the second year, 3 times in each of the third, fourth and fifth years, and twice in the sixth year. An exception is that, where a vigorous leguminous cover is maintained, fertilizer N is applied in the first year only.

From the sixth year the tree recycles a considerable amount of nutrients through leaf fall; and from about that time, corresponding with the start of tapping, the only nutrients needed are those

removed in the latex. Rubber is therefore not very demanding in terms of nutrient supply, and fertilization is generally restricted between 1 and 6 years after establishment.

The average amounts of mineral fertilizers applied in rubber estates are discussed in chapter 4.2 above. On sandy soils deficiencies of potassium and/or magnesium can be recorded. Nurseries and young plants usually receive a generous NPK fertilization to ensure a rapid growth of the immature plants. In the absence of a leguminous cover crop a slight application of NPK might be beneficial in the first years of growth, and there seems to be a positive correlation between growth in early years and yields during the first 6-7 years of tapping. Mature rubber gives usually modest but profitable yield responses to fertilizers.

High N and Mg levels can adversely affect the quality of the concentrate latex. Excessive Cu and Mn have a negative impact on the oxidative process of rubber. Within the tree excessive Mg and Ca can cause instability in the latex vessels, resulting in early pre-coagulation on the excised bark, and thus reducing the time of flow and yield.

**Pests and diseases** – The diseases to which *Hevea*, and in particular young trees, are susceptible are mainly fungal; they may cause considerable damage. Diseases affect roots, stem, branches or leaves.

The most widespread disease for *Hevea* is root rot, caused by *Fomes spp.*, *Armillaria mellea* and *Ganoderma spp.* which survive on the roots and stumps of trees in the course of land clearing. Treatment involves a preliminary sanitary inspection of the trees, followed by an application of a liquid, (micro)granular formulation of a fungicide (tridemorph or triadimenol) around the infected tree and its immediate surroundings. Trunks and stumps of dead trees must be removed from the field.

Another major disease is South American leaf blight, *Dothidella ulei*, the presence of which is mainly confined to South and Central America and Trinidad. It is the major limiting factor to rubber production in the New World. Other important diseases are:

- Powdery mildew (*Oidium heveae*): it attacks the young leaves at the start of the rainy season and causes a defoliation of the affected trees. Low temperatures associated with mist during leaf development seem to promote the development of this disease. Apparently, the disease is mainly restricted to Asia and Africa, and particularly to Sri Lanka, where it requires a regular sulfur treatment.
- Black stripe and leaf blight (*Phytophthora palmivora*): this is mainly observed on the tapping cut. It is serious in India and Central America. It is treated with fungicides and needs disinfection of tapping knives.
- Mouldy rot (*Ceratocystis fimbriata*): it only affects freshly tapped bark and is controlled by stopping or reducing tapping intensity and applying fungicides.
- Pink disease (*Corticium salmonicolor*): this is most serious in 3-4 year-old trees and is cured through a copper treatment.

Because of the characteristic smell of the latex, rubber is little affected by pests. Termites (*Coptotermes spp.*) and cockchafers (*Holotrichia spp.*) can be troublesome locally, while elephants, antelopes, wild pigs, deer, porcupines, rats and squirrels may cause damage to bark and trunk, particularly when young. The giant snail, *Achatina fulica*, causes damage in Indonesia.

**Fire risks** – *Hevea* is very sensitive to fire, in particular in the dry season. Many estates or part of estates are every year destroyed by fires, which originate from the customary burning of field plots as part of the traditional slash and burn agricultural system of the native population.

## 6. Tapping and Processing

Rubber is obtained by cutting into the rubber tree and collecting the latex. The cuts are made in the phloem tissues of the bark, cutting into the laticifer rings where the latex is stored (Figure 5). Once cut, these rings exude latex immediately. The force with which the latex comes out is dependable of the hydrostatic or turgor pressure. This force is high in the night and morning (up to 10-15 atmospheres) and diminishes in the afternoon. This explains why most tapping is done in the early morning. The process of cutting and capturing the latex is called *tapping* (Figure 6).

The yield of a plantation depends on the number, age and quality of the trees and on the skills of the tappers. It is largely affected by the intensity of the latex flow, the percentage rubber content in the latex and the capacity of the tree to replace latex between various tapping sessions. All these depend on tree age, clone type, climatic and soil conditions, and plantation management. The tappers have to be skilled to cut the tree deep enough to release the latex, but not too deep in order not to damage the cambium layer which causes the tree to stop growing. On industrial plantations the production of dry rubber per person/day ranges from 20 to 35kg.

### 6.1 Tapping

The objective of tapping is to collect the latex in the most efficient way. It is done by cutting the bark of the tree, forcing the vessels to release the latex. It is practiced throughout the year, except for a few weeks when the trees come into leaf.

The first tapping begins when 60% of the stand has reached a minimum girth of 50cm at 1m height in trees of 5 to 6 years old. Once the plantation has entered the tapping process it is productive for about 25 to 30 years. In a newly established estate tapping should start at the beginning of the rainy season.

The concept of excision tapping was developed by Railey in 1889. By this method a thin paring of bark is made from a sloping cut with a knife with a V-shaped cutting edge, leaving a grooved channel along which the latex can flow. By this procedure the latex flow is stimulated and the bark is renewed and can be tapped again. By making the tapping cut from top left to bottom right at an angle of 25-30° more latex vessels are severed and give 7-8% more yield. The angle also permits the latex to run down without overflowing. The latex runs along the cut and then down a vertical guide line, where a metal spout driven into the tree channels the latex into a cup, usually of glass or earthenware (Figure 6).

Figure 6. Tapping of *Hevea* in a descending half spiral. The latex runs via the spout into a cup (Courtesy L. Boedt, 2001).

A modern plantation will aim to achieve a maximum yield with a minimum number of tapping rounds. Various systems can be applied. When tapping is about to start, a tapping diagram of the bark is prepared, and the trunk is divided into 2 sections: panels A and B divided by a vertical line on the trunk (Figure 5). On panel A an outline of the future first tapping cut is drawn. It is traced at an angle 25° to 30° to the horizontal (top left to bottom right), more or less perpendicular to the latex vessels, and ends 120cm above ground level. Depending on the tapping frequency, this represents 15 to 20cm of bark being affected per year.

Tapping is done over half the trunk's circumference (panel A) and goes on for 2 years. Downward tapping follows a descending pattern (each tapping takes place below the preceding bark removal). From the third year on there is a shift towards panel B which is now tapped for 2 years, before

returning to panel A in the fourth year. Towards the 10<sup>th</sup> or 11<sup>th</sup> year (depending on how much bark has been removed), when the lower edge of the tap panel is reached, upward tapping starts from the first tapping cut made in the first year of exploitation. Later on, tapping returns to bark that in the meantime has regenerated.

Tapping starts early in the morning (at approximately 6a.m.) when the temperature and evaporation are low and the turgor pressure in the latex vessels is greatest. The latex is then left to flow for 5 to 8 hours. The tapping is interrupted during periods of vegetative rest. No tapping can be done during rain or if the panel is wet. On average tapping can be done over 85 to 140 days per year.

The tapper needs some tools: a tapping knife (serdang) or a gouge, a scraper for scraping the latex that has flowed over the trunk, a fungicide paste for treating any wounds, a whetstone for the gouge or knife, and a receptacle for collecting the latex.

The latex flow shows a distinct seasonal variation and is highest in the wet season. The yield of rubber can be increased by applying a stimulant (2.4D, copper salt, or the synthetic ethephon commercialized as Hevetex 5% PA and Ehtrel), which prevents plugging of latex vessels. Usually, the stimulant is applied by brush to the tapping cut at the end of the day. Other methods involve the application to the bark after it has been scraped or to the renewed tapping panel.

The task size varies greatly with the age and condition of the tree, topography and terrain access. Between 6 and 9a.m. a tapper can tap 400-500 trees on average, but tasks can be increased up to 600 trees. The tapper removes the coagulated latex from the previous cut and makes the new cut either upwards or downwards; tapping the high cut upwards gives rather higher yields than tapping downwards. The tapper returns to collect the latex at 11a.m. and carries it in pails to a central point for bulking and transport to the factory.

Three main problems hamper the tapping process. First, rainfall dilutes the latex and, therefore, tapping is interrupted during rain. A second problem is created by wounds through which the tree becomes more vulnerable to diseases and yields decrease. The third problem is over-exploitation resulting in a partial or complete cessation of the latex flow; the application of latex stimulants (see above) can hasten the effect.

## **6.2 Collection of Tapped Latex**

Two collecting systems can be distinguished: the *latex plus cup dregs*, and the *coagulation in cups* system. In the first system the fresh latex is immediately brought to the central treatment point; in the second system this happens only a few days later.

The latex plus cup dregs system is the most common form of latex collection. In this system the latex flow is collected in a 500ml or 1200ml cup fixed at the tree (Figure 6), to which an anti-coagulant (ammonium hydroxide) is added. Usually, the tapper initiates the cuts in a fixed amount of trees and then comes back (5 to 6 hours later) to the first trees where in the meantime the latex flow has ceased. Normally the latex cups are then emptied in a bucket and when full, the buckets are brought to a collection point where the latex is measured for its thickness by using a density meter. This is being done to avoid that certain employees would dilute the latex with water and obtain false higher yields. The latex collected by the tappers is first filtered and then stored in aluminum or galvanized iron tanks. If necessary ammonia is added to prevent premature coagulation due to the contamination by rain, poorly cleaned cups or plant debris. At the collection point there is a tank that, when full, is transported the same day to the factory for processing. In the tank the same additive is added to stabilize the latex.

Latex not harvested in this way is inferior in quality and is considered lower-grade rubber. This can be latex that is still in the groove, latex that is collected after harvesting, or latex that has flown on the ground. This corresponds to the second system of collection referred to above whereby the coagulum is only taken to the factory after a few days. Processing of this kind of latex is obviously more difficult due to the higher percentage of impurities, but allows for some more flexibility in the collecting roster. Also can in this way the number of tapped trees per tapper be increased (850 trees/day as compared to 600 in the first system)

### 6.3 Processing

On arrival at the factory the latex is measured for its contents of the anti-coagulum that was used in the plantation, and the amount of ammonium is adjusted in the storage tanks to around 3.5 to 4 g/liter of latex. The latex may be diluted with water to obtain a constant dry rubber content (DRC). The normal percentage of high rubber content in concentrated latex is 60%. Thereafter, the latex is homogenized in large containers with a capacity of 5,000 to 20,000 liters and manufactured in different commercial products.

*Concentrated liquid latex* – Certain industries like the surgical field and the makers of adhesives need concentrated liquid latex, i.e. latex with a high rubber content (60%). The harvested latex is in this case centrifuged to expel the serum or aqueous substances. Separation is possible on the basis of the different specific gravity of the various components. The latex is stabilized by adding ammonia. Other processes for obtaining concentrated latex are electro-decantation and evaporation.

In the preparation of *ribbed smoked sheets (RSS)*, the latex is diluted with water to 12-15% DRC and is then restrained using a finer screen. It is poured into the coagulating tanks and coagulated by adding acidic or formic acid (at a concentration of 3-5g per kg of rubber), mixing thoroughly and quickly. Froth formed on the surface is skimmed off as this would cause bubbles in the coagulated rubber.

The rubber coagulates into a thick curd and the clear serum is run off. By using separators in the tank, thick sponge-like sheets are produced, and these are passed 6-8 times between rollers of decreasing distances apart to produce a sheet not more than 2-5mm in thickness; then through grooved rollers to produce a corrugated or ridged surface. The sheets are dried by hanging in a smoked house for 4 days at about 50° C. The purpose of the drying and smoking is to eliminate as much water as possible (less than 0.5% may remain) and to impregnate the sheets with preservative substances to prevent mould. When they leave the smoke-house, the sheets of rubber are inspected visually for impurities and air bubbles. The final product should be a uniform golden-brown, semi-transparent sheet, without opaque spots or blemishes. The rubber is then graded into quality classes RSS1 to RSS5, and packed for export in bales of 100, 80 or 35kg respectively.

*Crepe rubber* has been processed in a quite similar way, but it is produced by passing the coagulated sheet rubber through special shearing rollers running at unequal speeds. It may be bleached by adding sodium sulfite to the latex. Drying is done in open air, or in special houses with controlled heat, but not smoked.

*Granulated rubber* is obtained by squeezing first the coagulated sheet between two crushers to expel what is left of the coagulum serum, followed by another squeezing between two grooved rollers rotating in opposite directions to homogenize and wash out the coagulum, resulting in fragments. These are then crumbled in a shedder. The formed granules (5mm) are subsequently dried at high temperature (120-130° C) for about 3 hours.

*Lower-grade rubber* has many impurities and is therefore first soaked in water before being passed to a slab cutter and a pre-breaker, which breaks up the chunks of agglomerated coagulum, reducing them in size to small pieces of 3-4cm in diameter.

For more details on rubber processing the readers are referred to Delabarre and Serrier (2000) and Boedt (2001).

## **7. Utilization and Use**

The main product of the rubber tree is the latex, used as a source for natural rubber. Besides, the tree can be used for its seeds and timber.

*Rubber* – Natural rubber accounts for about 30% of global rubber production. The choice for using natural or synthetic rubber or a combination of the two is determined by economic and technical factors. The successful introduction of synthetic rubber (isoprene) originates from the shortage of natural rubber in the Second World War when, because of the Japanese invasion, most of the rubber production of Southeast Asia was cut off for western countries. Natural rubber production was also unable to keep pace with the industrial world's rapid economic growth, so synthetic rubber quickly became an excellent alternative. Synthetic rubber is, however, a petroleum derivate and its production price varies with world energy prices.

Today some 70% of the total natural rubber consumption is in the manufacture of tyres, tubes and other items associated with automotive transport. It is estimated that some 50,000 different products are made from natural rubber directly or indirectly. About 6% of the world's rubber is used for footwear, boots, shoes, soles or heels, and 4% for wire and cable isolation. Miscellaneous manufactured articles include rubberized fabrics, shock absorbers, washers and gaskets, transmission and conveyor belting, hoses, sports goods, household and hospital supplies, contraceptive appliances, paints, etc. Sponge rubber from foamed latex is used in upholstery, mattresses, etc.

Vulcanite (or ebonite) is a hard highly sulfurized rubber used in electrical and radio engineering industries and as protective lining in chemical plants. Rubber powder with bitumen is used for road surfacing.

*Seeds* – The seeds consist of an oily shell and a kernel; the latter contains 30-50% of oil. Amazonian Indians use the kernels as human food. The oil in the shell is, after processing, similar to linseed oil, and is used as an ingredient in paints, varnishes and soaps. The residual cake after oil extraction is high in protein and carbohydrates, and after elimination of its toxic cyanhydric acid content by boiling for 15 minutes at 350° C, can be used to feed cattle and poultry.

*Wood* – Old rubber trees provide a valuable wood source, which can be used for either domestic or industrial fuel (caloric value 4,500 – 4,700 kcal/kg), the production of charcoal, the manufacture of pulp for the paper industry, for furniture and medium-dense fiber board, packing cases and pallets, etc. Delabarre and Serrier (2000) estimate that a 30 year old plantation produces between 150 and 200 tons/ha of green wood.

## **8. Production and Trade**

Rubber is a natural commodity and, therefore, production levels are not constant. They vary according to the planting material, climatic and soil conditions, and crop management. Average yields of unselected seedling rubber in India are about 350 kg/ha dry rubber per annum, and in Malaysia 450-550 kg/ha. Modern clones yield on average between 1 and 1.5 tons dry rubber per ha



in industrial plantations in Asia (with peaks up to 2.2 tons/ha), and 1.5 to 2 tons (with maxima up to 2.5 tons) in Africa. Latex yields extend up to 25-30 years. On smallholders' plantations yields are about 80% of industrial plantations.

At the beginning of the 20<sup>th</sup> century the world's supply of rubber came almost entirely from wild trees in Brazil, and the world's consumption of rubber from *Hevea* and other natural sources was only 52,500 tons. The annual consumption doubled nevertheless each decade. The loss of natural rubber from Malaysia and Indonesia due to the Japanese occupation during World War II led to the use of many other sources of natural rubber, including the Russian dandelion, the Mexican guayule, and in particular in the rapid development of synthetic rubber production. The equilibrium was reached in 1961, when over 2 million tons of both synthetic and natural rubber were produced.

Natural rubber entering world trade comes nowadays almost entirely from *Hevea brasiliensis*. With rising production costs and competition from synthetic rubber, the emphasis is now again on replanting with greatly improved planting material rather than expansion in planted area.

Although, ecologically speaking, Africa offers the best conditions for growing rubber, production on the continent is limited, mainly for reasons of political instability. To date, the major production zone of natural rubber is Asia (92% of all production), in particular the Far East. Malaysia (1,540 Mt in 1979-81; 589 Mt in 2003) was for a long time the biggest producer, but this role is now taken over by Indonesia and Thailand (Table 1), mainly because much rubber land in the country has been converted into oil palm. This evolution has a socio-economic reason related mainly to the shortage of labor, too high labor costs, and the growing demand for oil palm. Thailand (2,615 Mt) is now the biggest rubber producer in the world, with Indonesia (1,792 MT) being second. Vietnam has in the last 25 years increased its production by a factor 10.

Africa produces 7% (421 Mt in 2004) of the world's supply of natural rubber, with Nigeria (112 Mt), Madagascar (108 Mt) and Ivory Coast (123 Mt) as the biggest producers, followed by Liberia and Congo. The production in these countries is, however, still low when compared to their much higher yield potential. Moreover, production may vary from year to year due to the political instability in these countries.

In South America the only important rubber-producing country is Brazil (96 Mt or hardly 1% of the world production). Although it has increased its production by a factor 4 over the past 15 years, it has no longer enough rubber to cover its own demands.

The countries importing rubber in decreasing amounts are: United States, Russia, Germany, United Kingdom, Japan and France; it is not surprising that these are the main car producing countries in the world. The annual consumption in the US is now about 10kg per caput compared with 0.5kg per caput for all the other countries combined.

Table 1. Natural rubber production in the world (Source: FAO Yearbooks)

At present more than 935 million ha in about 40 countries are devoted to rubber tree cultivation with a production of about 7,5 million tons. In 2020 the global demand for natural rubber is estimated at 12 million tons (Venkatachalam et al., 2007. If oil prices remain high the production of synthetic rubber may be reduced in favor of natural rubber.

## **9. Environmental and Social Constraints of Plantation Crops**

### **9.1 Land Tenure**

The establishment of an industrial plantation of 3,000 to 5,000 ha often leads to land tenure problems. In countries where former colonial powers had made provisions for the delimitation of selected areas for environmental protection - the so-called “*Forêts Classées*” in French West Africa – there existed extensive reserves of natural forest land, whereby the native population maintained limited hunting and firewood-collecting rights, but where no agriculture was allowed. After independence in the 1960s some countries, like Ivory Coast, made these classified areas available for large-scale commercial activities, including oil palm and rubber estates operated in a joint venture between private companies and the state.

At that moment, however, the traditional authorities (being the customary owners of the land) in Ivory Coast claimed that the original agreements on the protection of native land were violated and that at least part of the economic benefits had to be returned to the local community. While in some countries many of these claims are still pending in court, it was at least agreed that the use of land by operating companies should be settled by law. Hence, in Ivory Coast it became subject to the Land Law 98/750 of 23 December 1998 in force. In first instance, the land was leased for a limited period of 99 years. (Note that under customary law in Africa the land belongs to God and can not be alienated *in se*, but only leased). Moreover, compensation had to be paid for the use based on the cropping pattern as defined by the legislation.

This agreement had a direct impact on the recent extensions of estate land. The *ad hoc* legislation in Ivory Coast stipulates that, at first, a full agreement has to be reached between the parties on the length of the lease (often ranging between 30 and 99 years), and that an indemnity has to be paid for the crops that are still on the field. The *Presidential Decree of March 12, 1996 on Indemnities for Cultivated Land* has fixed the level of such indemnities, i.e. 100,000 (minimum) to 500,000 CFA/ha (maximum) for a small coffee plantation, or 100 to 500 CFA per tree; 240,000 to 600,000 CFA/ha for a pineapple field, or 10 to 60 CFA per individual plant; 40,000 to 100,000 CFA/ha for cassava, etc. At this period the US\$ valued 320-350 CFA. The exact price between the minimum and maximum amounts was fixed in common agreement on the basis of the healthiness of the crops and the anticipated loss of income.

## 9.2 Land Clearing

Another important environmental aspect of estate farming is the land clearing. The traditional method of land preparation involves the complete destruction of the former vegetation by burning either the forest or the former oil palm, coconut or rubber stands. This procedure has the advantage that it facilitates land access and reduces the risk for pests and diseases. However, it also causes air pollution and results in loss of organic matter, viz. biodiversity.

Nowadays, a more environment-friendly method is applied, the zero burning technique (*see also: Growth and Production of Oil Palm*). This method, initially developed in the Golden Hope Plantation in Berhad, Malaysia, and awarded by the UNEP Global 500 Medal in 1993, involves the felling of the old trees, shredding the trunk tissues into 5-10cm thick pieces, and then spreading them thinly and evenly in every row for the tissues to decompose. This technique offers the advantage of creating no (or only limited) air pollution, as burning is restricted to the under-bush vegetation, and of recycling organic matter and nutrients, thus saving some 20-25% of inorganic fertilizer input during the first 4-5 years of plantation. Most estate cultivation is now more or less strictly this procedure.

It has to be recalled, however, that the zero burning technique is strongly contested in smallholders' plantations because this interferes with the tradition of dry-season burning, whereby small-scale hunting and the catchment of small field animals supply an extra food supply at a moment that food

stocks are nearly empty, and that this hunting constitutes the only available fresh meat source for the local population in between two production seasons.

### **9.3 Use of Agrochemicals**

Rubber (as well as oil palm and coconut) estates are quite sensitive to pests and diseases and, therefore, require a strict phyto-sanitary control, which in the past was to some extent overcome by seasonal burning. In the 1980s and 1990s this control was mainly taken over by the rather extensive use of herbicides and pesticides. Nowadays, there is however a very strict regulation on the use of these agrochemicals. These rules are enforced by national legislations and by directives issued as part of the contracts between the commercial companies and international funding organizations. Norms for these regulations refer generally to the ecotoxicity and safety levels defined by WHO, FAO and World Bank/IFC (*see also: Land Use Management and Conservation Agriculture*). Although not all these toxic products have already been replaced by non-toxic alternatives, they are gradually banned from the field stock.

Phyto-sanitary products are much less used in smallholders' plantations, not only because small farmers can often not pay for the extra costs, but also because the handling of these products is dangerous for people with no experience in these matters. Disease control in these situations is therefore more focused on manual treatments complemented by *ad hoc* interventions by specialized teams at the effective outbreak of pests and diseases. The strategy in these smallholder's groves is to keep harmful events below economically acceptable levels, and especially to avoid that the event spreads over the industrial plantation.

### **9.4 Social and Rural Development**

Large-scale estates, when managed in an open and socially-friendly way, can be major tools in rural development. The industrial plant does not only provide work for quite a number of laborers (often a few hundreds) employed in the field and mill operations, but stimulates also actively the establishment of schools and dispensaries, the development and maintenance of a proper road network, the partial or total reconstruction of local villages and improvement of housing facilities in general, and the installation of a safe-drinking water network. The author has experienced himself how the negotiation of an extension of an estate was more focused on the opening of an access road or the reparation of a broken bridge than on purely monetary benefits for the local community. The Southwestern region of Ivory Coast around the local centers of San Pedro, Sassandra and the Liberian border has over the past 40 years been converted from an almost inaccessible dense tropical forest area into a well developed part of the country almost exclusively as a result of the activities of rubber and oil palm estates.

The main international funding agencies like the World Bank, IFC or UNDP have in the past decennia actively promoted the participation of smallholders in agro-industrial development projects. A combination of a central nucleus of industrial estate with a number of smallholders' plantations has advantages for both parties. From a technical point of view the production of smallholders' groves is often slightly delayed in time as compared to the industrial fields, and this allows to better spread the activities of the oil mill (in the case of palm oil production) or to optimize the capacity of the rubber plant.

On the other hand, the industrial estates provide technical assistance to smallholders in delivering selected planting material, pre-financing fertilizers and other commodities, or in providing complimentary phyto-sanitary services. Though the smallholders generally remain free to whom to sell their produce, the estate is often asked to commercialize most or part of the smallholders' oil

palm produce, often at pre-fixed prices. In this respect this form of collaboration pumps money in the local economy and provides a guaranteed source of revenue for the families.

## 9.5 Biodiversity

The traditional concept of an industrial rubber plantation (like all other larger estates) in one single bloc of 3,000 to 5,000ha conflicts with the principle of ecological biodiversity. This is the problem of each monoculture, which can never be solved in its totality, though reasonable compromises are still possible. Therefore, the parties have to go back to the soil map and to the differentiation between the most suitable - mostly well drained upland soils - and less suitable areas, i.e. the flooded areas and valleys. With this in mind, it is always recommended to keep most valleys out of production, and maintain these as untouched natural biotopes. The only point further to solve is then to avoid that those biotopes remain isolated patches between which no free access for plants and animals is allowed. Care must therefore be taken to allow for an open network between such natural patches, even at the expense of some corridors in otherwise suitable oil palm or rubber land.

It is obvious that good agreements have to be made between plantation managers and environmentalists on the way both land use types have to be protected. This involves from the side of the planters that no fertilizers or pesticides/herbicides are used in the immediate neighborhood of protected biotopes to avoid chemical pollution of the latter. On the other hand, the plantations have to be protected for damage inflicted by wildlife, especially by larger animals like elephants, porcupines or monkeys. In an agreement between an oil palm plantation and the Toai National Park in South West Ivory Coast, the salary of a number of rangers was paid by the oil company to safeguard its border with the park.

## Glossary

- Anthesis:** The time the flower is expanded and is receptive to fertilization.
- Axil:** The upper angle between the leaf and the stem.
- Bog:** Marsh
- Cambium:** The layer of tissue between the bark and wood in woody plants, from which new wood and bark develop.
- Carotene:** A red or orange-colored compound, found in carrots and some other vegetables, and changed into vitamin A in the body.
- Clone:** A group of plants originating by vegetative propagation from a single plant and therefore of the same genotype.
- Coagulation:** The change from a fluid to a soft, semi-solid state.
- Cortex :** Bark, as of a tree.
- Ecozone:** Zone or area with similar ecological characteristics.
- Ecotoxicity:** A poisonous quality or state of the ecosystem.
- Endocarp:** The innermost layer of the pericarp or fruit wall when its texture differs from the outer layer; it may be hard and stony as in plums and peaches, membranous as in apples, and fleshy as in oranges.
- Entomophilous:** Insect-pollinated.
- Heterozygous:** Having unlike alleles at corresponding loci of homologous chromosomes ; an organism can be heterozygous for one or several genes.
- Hybridization:** The crossing of individuals of unlike genetic constitution.
- Hypocotyl:** The part of the axis below the cotyledons in a seedling.
- Inflorescence:** The arrangement and mode of development of the flowers on the floral axis.
- Isoprene:** A colorless, volatile liquid prepared by the dry distillation of raw or synthetic rubber; here mainly synthetic rubber.
- Latex:** A milky liquid in certain plants and rubber trees.
- Laticiferous:** Bearing, producing or secreting latex.
- Meristem:** Undifferentiated tissue of the growing point whose cells are capable of dividing and developing into various organs and tissues.
- Mesocarp:** The middle layer of the pericarp or fruit wall which is often fleshy or succulent.
- Monoecious:** When the male and female flowers are separate, but borne on the same plant.
- Parenchyma:** A soft tissue of roundish, thin-walled cells in a plant stem or the pulp of fruits.
- Phloem:** The non-woody conducting tissue in plants, chiefly concerned with the transport of nutrients.

**Pollination:** The transfer of pollen from the dehiscent anther to the receptive stigma.  
**Ppm:** Part per million.  
**Primordium:** The first recognizable aggregation of cells that will form a distinct organ.

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## Biographical Sketch

Willy Verheye is a former, now retired Research Director at the National Science Foundation, Flanders, and a Professor in the Geography Department, University of Ghent, Belgium. He holds an MSc. in Physical Geography (1961), a PhD. in soil science (1970) and a Post-Doctoral Degree in soil science and land use planning (1980).

He has been active for more than thirty-five years both in the academic world, as a professor/ research director in soil science, land evaluation, and land use planning, and as a technical and scientific advisor for rural development projects, especially in developing countries. His research has mainly focused on the field characterization of soils and soil potentials, and on the integration of socio-economic and environmental aspects in rural land use planning. He was a technical and scientific advisor in more than 100 development projects for international (UNDP, FAO, World Bank, African and Asian Development Banks, etc.) and national agencies, as well as for development companies and NGOs active in inter-tropical regions.

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