Tropics with year-round rain

15.1 Distribution

Most of theTropics with year-round rain lies within latitudes 10°N and 10°S. It extends, however, both north and south of the equator to about latitude 20° where the ecozone is in the area in which the winter trade winds and monsoonal rains, mostly orographic rains, supplement the summer rainfall. The total area is about 12.5 million km^2, 8.4% of the land mass.

The boundary to the Subtropics with year-round rain is determined by temperature and runs along the 18 °C isotherm for the coldest month.Towards the Tropics with summer rain, the boundary is determined by a mean annual precipitation of about 1,500 mm. Soil, relief, vegetation and land use have some similarities with the moist savanna zone of the Tropics with summer rain. This justifies to a certain degree a combination of both which then is termed *humid tropics*. On Fig. 15.1 the moist savanna zone is shown as a transition zone to the Tropics with year-round rain.

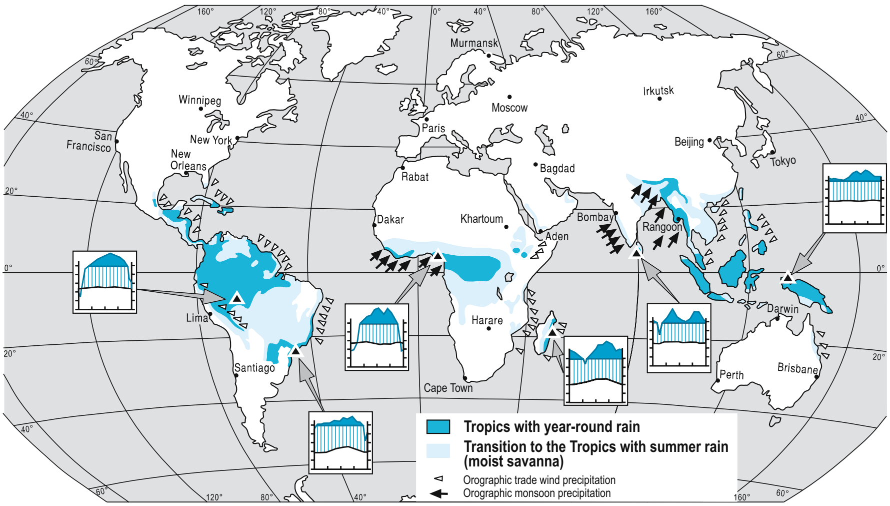


Fig. 15.1. Tropics with year-round rain.

15.2 Climate

Rainfall is year-round, especially near the equator where there is no noticeable seasonality at all. The strongly positive radiation balance is almost the same throughout the year because of the uniform length of day. Temperatures remain constant year-round at 25 to 27 °C, with a diurnal range of 6 °C to 11 °C. Convection rainfall predominates in the zone. There are two seasonal maxima shortly after the sun is at its highest point in April and October. In the months between precipitaion declines but there are seldom more than 2 to 3 months without any rainfall. Plant growth continues throughout the year, although in many areas it slows for a short period during which leaves fall or flowers develop.

Individual precipitation events are intense, short thunder showers are frequent and daily totals often more than 50 mm. Mean annual precipitation ranges from 2,000 to 4,000 mm. Annual cloud cover is often over 60% and 40% of the global radiation is diffuse radiation, the highest ratio of all ecozones. Much of the radiation intake is used for evaporation and transferred as latent heat. Relative humidity is very high throughout the year. Annually, evapotranspiration consumes over 1,000 mm, maximally over 1,200 mm, of water, more than any other ecozone and more than from the open sea in these latitudes. The plant surface area of the rainforest is very large and the supply of moisture from the soil is uninterrupted, even where there is a regular dry season because moisture continues to rise from the deep roots. There is a continuous and large amount of energy available for evaporation throughout the year and total actual evaporation almost reaches the potential evaporation.

In the areas of tropical forest, the climatic characteristics valid for the ecozone as a whole apply mainly to the canopy and the area immediately above it. The climate of the trunk area within the forest and particularly the climate in the air layer immediatly above the ground vary considerably for a number of reasons. First, sunlight is diminished to about 1 to 3% on the forest floor also, the ratio of red/infrared radiation energy sinks to 0.4 and less, instead of 1.0 or more, which affects germination and other growth processes. Secondly, the mean air temperature is equable with a small diurnal range of 3–4 °C. In the canopy, however, the midday temperatures reach up to 32 °C but near the forest floor it is usually 4–7 °C less. At night the temperatures are everywhere about 20–22 °C. Thirdly, the constantly high relative humidity of 90–100% impedes transpiration and interferes with mineral uptake from the soil, except on the surface of the canopy which at times has a relative humidity of only 50% and therefore a high saturation deficit. Leaf temperatures can rise up to 40 °C. Fourthly, the winds that accompany thunderstorms are felt much less within the forest and hardly at all on the forest floor. For this reason, and also while photosynthesis processes and the uptake of CO_2 do not play an important role, the release of carbon dioxide as a result of decomposition within the litter and soil leads to a concentration of CO_2 of 400 ppm during the day and 450 ppm at night; in the canopy, values during the day sink to nearly 300 pp (Fig. 15.2).

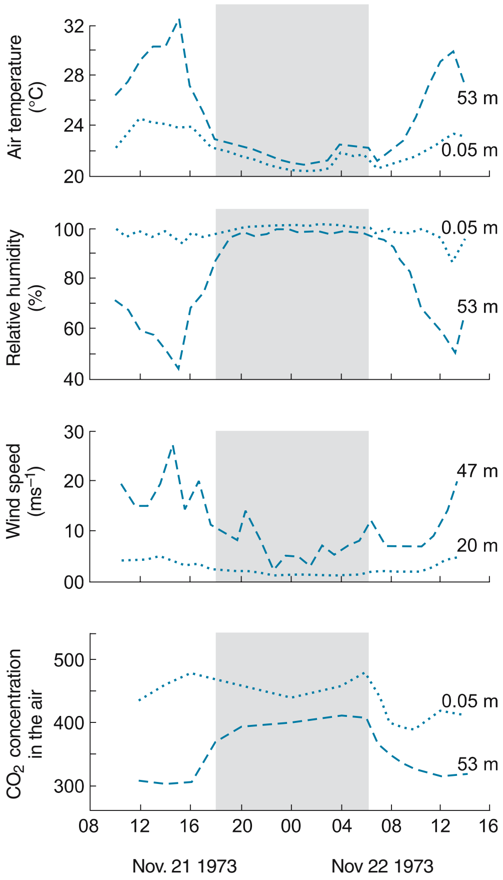


Fig. 15.2. Diurnal changes in temperature, relative humidity, wind speed and CO_2 concentration in the atmosphere above the canopy and in the trunk area in a lowland rain forest near Pasoh in western Malaysia. The surface of the closed canopy is at 45 m. Emergent trees reach 55 m. The leaf area index is 8. Source: Aoki et al. 1975

15.3 Relief and drainage

Chemical weathering is of major importance in the tropical rainforests. High soil moisture content, soil acidity and year-round high temperatures accelerate the process. Also, temperatures in the soil can be a few degrees higher than the air temperature near the ground because of heat released during humus formation.

Mechanical weathering is unimportant. Any disintegration of bedrock is a result of pressure release. Unlike the dry and and seasonal tropics, there is little material prepared by mechanical weathering for chemical weathering. Bare rock, especially if there are no joints and the exposures are steep is not decomposed.

Very deep layers of soil and *regolith* have formed over very long periods, often on old land surfaces, as a result of chemical weathering. Below the regolith is saprolite, decayed rock up to 100 meters in depth that lies above the bedrock. The regolith contains hardly any of the minerals present in the original bedrock. Relatively stable secondary products dominate such kaolinite, gibbsite, hematite and goethite so that there is little solution transport in the streams.

Solution processes in areas of limestone in the tropics have led to the formation of karst landscapes. Tower karst and cone karst up to 100 meters in height are characteristic for areas of the tropics with rainfall during much of the year.

Denudation surfaces are widespread in the Tropics with year-round rain, especially in areas of residual relief. Where there are young fold mountains and volcanoes, slopes are steep and incised by streams in valleys that are separated by narrow ridges. Because of the high precipitation, stream network densities are also high.

Little or no wash denudation can take place in the tropical forests.The rain falls on the stories of the canopy of the rainforest and, after a period of time, from 5 to 50% reaches the ground as drops, much of it as through flow and enters the soil. Moisture not taken up by the roots flows to the groundwater.

Mass movements are relatively frequent in the ecozone. Landslides, mud and earth flows all occur if the regolith becomes saturated and positive pore water presssure develops within the mass on the slope. Even though this form of denudation process takes place irregularly, it is the most important form of slope denudation in the tropical rainforests. Over time all slopes are probably denuded by mass movements which then reoccur in the same place when the regolith cover has developed again.

15.4 Soils

Some soils in the Tropics with year-round rain are similar to the soils in the Tropics with summer rain and the Subtropics with year-round rain. Ferralsols are the most widespread soil type. Plinthosols, Ferralic Cambisols, Ferralic Acrisols and Podzols are also present. Acrisols are common in Southeast Asia, West Africa and in the tropical rainforest of South America (Chap. 12). Lixisols are also important in some areas (Chap. 14). Table 15.1 shows the characteristics of the soils most typical for the ecozone.

Ferrasols are found for the most part on older land surfaces. They have developed in tropical rainforests over a very long time, often beginning in the Tertiary, on various bedrocks and under continuously wet and warm conditions. Acrisols have a similar but less advanced development.

Ferralsols are from light yellow to deep red and have a low humus content. The ferralic B horizon is very deeply developed, uniform in color and texture and without clay accumulation. Clay immobility is typical of Ferrasols. Weatherable silicate is less than 10% in the 50 to 200 µm fraction of the B horizon and the texture is sandy loamy and fine grained with clay forming about

Table 15.1. Chemical characteristics of soils in the humid tropics at the surface (upper 0–20 cm) and in the subsoil (70–100 cm)

Chemical characteristics	Ferral-sols	Acri-sols	Lixi-sols	Cambi-sols	Areno-sols	Podzols
pH H_2O (1:2.5)	4.8 (5.0)	4.8 (4.8)	6.4 (5.9)	5.3 (5.5)	5.3 (5.8)	4.5 (4.8)
pH Kcl (1:2.5)	4.1 (4.5)	4.1 (4.0)	5.5 (4.6)	4.6 (4.5)	4.1 (5.1)	3.7 (4.4)
Organic carbon (%)	2.3 (0.4)	2.0 (0.4)	62.2 (0.3)	2.3 (0.4)	0.8 (0.1)	5.0 (0.7)
C/N ratio	16 (9)	14 (8)	17 (7)	11 (8)	16 (12)	23 (11)
Exchangeable bases (cmol(+)kg^{-1})	1.8 (0.7)	2.2 (0.6)	21.2 (16.8)	11.5 (9.0)	2.0 (2.0)	1.0 (0.1)
Exchangeable Al (cmol(+)kg^{-1})	1.4 (1.1)	1.5 (2.2)	0.0 (0.3)	0.1 (0.0)	0.1 (0.0)	1.0 (0.2)
CEC_{pot} (cmol(+)kg^{-1})	8.8 (4.0)	9.9 (6.9)	22.7 (25.0)	19.3 (14.9)	6.6 (3.2)	20 (4.7)
Base saturation (%)	19 (19)	26 (12)	87 (67)	49 (52)	44 (39)	18 (43)

Values in parenthesis for subsoil
The values are means of 30 Ferralsols, 33 Acrisols, 9 Lixisols, 30 Cambisols, 5 Arenosols and 6 Podzols.
Exchangeable bases: Ca^{++}. $K^{+,}$ Mg^{++} and Na^{+}

Source: Kauffman et al. 1998

8% of the fine earth fraction. The clay fraction is mostly of kaolinite, iron and aluminium oxide and hydroxide and silt/clay ratios are low. Most of the sand and silt particles are of quartz. Ferrasols are acid to very acid with a low cation exchange capacity and base saturation. ($CEC_{pot} < 16\,cmol(+)\,kg^{-1}$ clay and $CEC_{eff} < 12\,cmol(+)\,kg^{-1}$ clay). Ferralitization is the soil process that leads to the development of a ferralic B horizon. Included is the desilification process in which silicate is mobilized and washed out and without which the residual enrichment of kaolinite and sesquioxides cannot take place.

Iron (Fe) and aluminum (Al) oxides have a tendency to develop stable soil aggregates of sand sized grains (pseudosand) from a few millimeters to centimeters in size. Ferrasols with a high clay content have, therefore, a large proportion of stable intergranular large pores which makes them highly porous. Even after heavy rainfall they are not easily eroded and can still be worked. Of the water remaining in the soil, a large part is dead water within the soil aggregrates and not usable for plants. The maximum amount of usable water is usually less than 100 mm per one meter in depth (Spaargaren and Deckers 1998). Despite the year-round humid climatic conditions, shallow rooted plants are subject to stress from drought if there is a lack of rainfall for some time.

Plinthic Ferralsols have an upper B horizon of *plinthite*, a mixture of kaolinite, sesquioxides and quartz, high in iron and with a low humus content. The concentration of iron is a residual enrichment and appears in red flecks, The kaolinite concentrates as white flecks. Soils are firm in consistency and the porosity poor. Denudation rates on the slopes of these soils are high but on level ground they cause stagnation and flooding. If there is repeated drying out on fields after the top soil has been removed, the plinthite hardens as crust or as individual aggregrates, known as *ironstone*, that is irreversible. Formerly these soils were described as *laterites*.

The new FAO classification defines soils with a horizon at least 15 cm thick within 50 cm of the soil surface that has more than 25% plinthite and therefore a plinthic horizon, as Plinthosols.

Ferralic Cambisols are an indication of an early stage of ferralitic weathering. Unlike the Ferrasols, they contain unweathered minerals and have a higher cation exchange capacity than Ferrasols but lower than other Cambisols. Ferralic Cambisols are relatively fertile and in West Africa are developed in hilly regions where the top soil has been repeatedly removed by wash denudation so that soils remain in the early stages of formation. Leptisols are also often in these areas.

Ferralic Arenosols are sandy soils with a kaolinite clay component. In the tropics where rainfall is high, they are probably developed on relatively recent deposits of material that originated in highly weathered soils such as Ferrasols and Acrisols. The silicate content is low also the cation exchange capacity and the water storage capacity. The field capacity is often only about 10%.

Podzols are developed on sandstone and sediments with a high quartz sand content, often well over 80%, similar to the Arenosols. They are some of the poorest soils in the tropics and unlike all other soils in the zone, contain a high proportion of low quality dead organic matter with a low C/N ratio. The quantity of exchangeable nutrient ions is smaller than in many Ferralsols. Podzols are developed in the area of the Rio Negro in Brazil and on the Indonesian islands of Kalimantan and Sumatra, but cover in all only about 1% of the tropics with high rainfall.

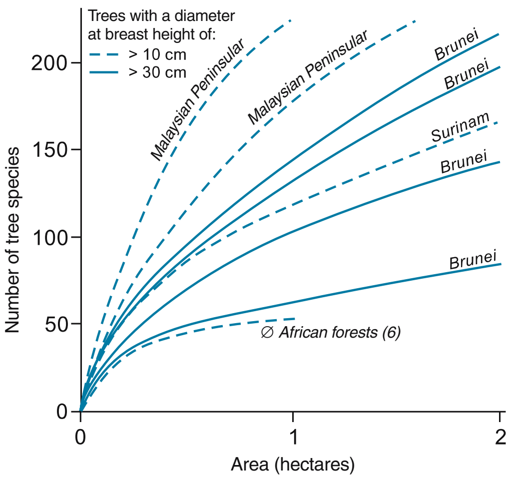


Fig. 15.3. Number of tree species per hectare. The curve for Africa is based on the mean of 6 surveys. The other curves are based on one survey

15.5 Vegetation and animals

The *evergreen tropical lowland forest* is the typical plant formation in the ecozone.

Clearing, especially during the last twenty years has reduced the area by more than half. With clearing, large amounts of *carbon dioxide* (CO_2) are released from the biomass and the humus. Even when CO_2 is bound again in crops, plants, pastures, forestation or secondary forest and the supplies of organic matter in the soils recover after a few years, there is still an overall loss. Whether this in reality reaches a total of $1.9\,\mathrm{Gt\,C\,a^{-1}}$ as shown in the global balance of the global carbon circulation is uncertain (Fig. 8.13). The exact total forest cover destroyed is unknown, also it is very difficult to estimate how much CO_2 is bound when the forest regenerates or clearings are cultivated.

15.5.1 Structure of the tropical rainforest

Tropical rainforests have a large number of species, more than one third of all known species in the world are from the tropical rainforests. There is also a wide *diversity of species*. For trees alone the number species per hectare can reach over 100, with at most only 2 or 3 trees of a single species in the hectare (Fig. 15.3). A comparison of the height and density of the plant coverage in the tropical rainforest compared to the Temperate midlatitudes is shown in Fig. 15.4. In the tropics there are several hundred trees, maximally about 1,000, with a trunk diameter of at least 10 cm at 1 meter above the ground. The total basal area of all trunks is at least 25, usually 30 to 40 $\mathrm{m^2\,ha^{-1}}$.

The *leaf area index* in tropical rainforests at 8 to 12 is very high. The leaf stories in the forest can be measured for leaf density using the leaf surface area in m^2 per cubic meter volume of stand or the biomass (leaf and/or wood mass) per meter of height in $\mathrm{kg\,m^{-3}}$ (Fig. 15.5). Each story has light intensity characteristics and other climatic parameters that vary from the means for the forest as a whole.

Often over 70% of the species in a forest are broad-leaved trees of which nearly all are evergreen. Both trees and herbaceous plants are hygrophytes and adapted therefore to the constantly high humidity. In addition to the trees, there are many species of lianas and vascular epiphytes. *Lianas* are woody climbing plants that reach considerable heights and use relatively limited nutrient supplies because they are supported by other plants. Their share of total basal areas of the trunks is low but at the canopy level their share of the leaf mass is high (Table 12.1). Over 90% of the liana species are in the tropical rainforests where they also provide a large share of the total flora, both in variety and quantity.

Epiphytes are usually herbaceous plants which grow on the trunks or branches of trees but without any indication that they are parasites. They include many orchids, the majority of which are epiphytes. Also widespread are ferns and

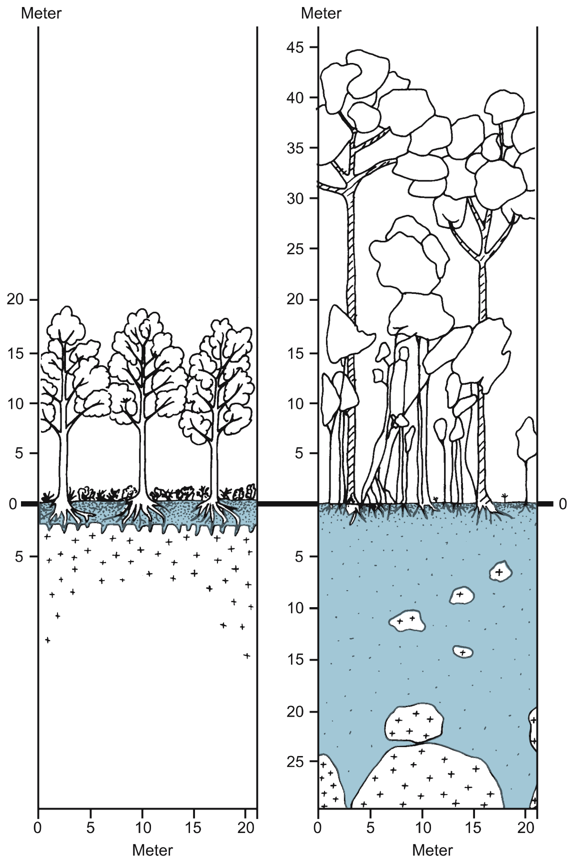


Fig. 15.4. Profile of a deciduous forest in the Temperate midlatitudes and of a tropical rain forest. Characteristic for the rain forest is the height of the trees, dense stands with large diameters, several levels of tree growth, underdeveloped herb layer, incomplete litter layer and, in relation to tree height, shallow rooting systems in humus poor deep soil that lies above decomposed bedrock

Bromeliaceae, mosses and lichens. Figure 15.6 shows the nutrient sources of epiphytes. The tallest trees in the canopy and many of the epiphytes are mesophytes or xerophytes.

Many broad *leaves* in the tropical rainforest are undivided in the middle, unlike leaves in the savanna. They are also larger, from 10 to 20 cm long, softer and darker green than leaves in other ecozones. The large leaves of many species encourages photosynthesis in limited light conditions. Some leaves also have hydathodes through which water is actively pressed into the saturated air. In many varieties the stomata are raised above the leaf surface and the total pore area, the product of the pore density per mm^2 and maximum pore width, is up to 3% of the leaf surface, higher than anywhere else. Frequently the leaves

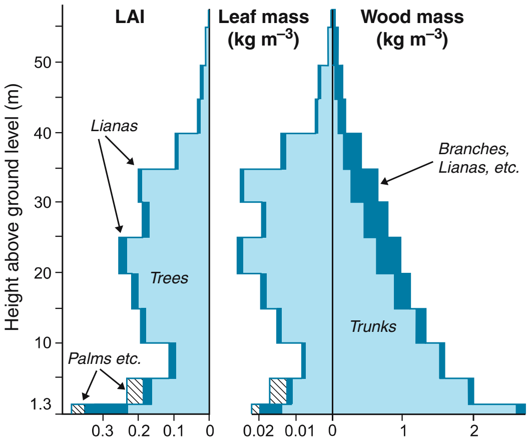


Fig. 15.5. Vertical structure of rain forest near Pasoh, Malaysia. Values at 5 m intervals of leaf area index, the leaf mass (kg per cubic meter), and, less defined, the wood mass of the branches and lianes, together indicate three forest stories at < 1.3 m, 20–25 m and 30–35 m. The rapid decrease in values above 40 m coincides with the story above the canopy composed of emergent trees. Source: Kato et al. 1978

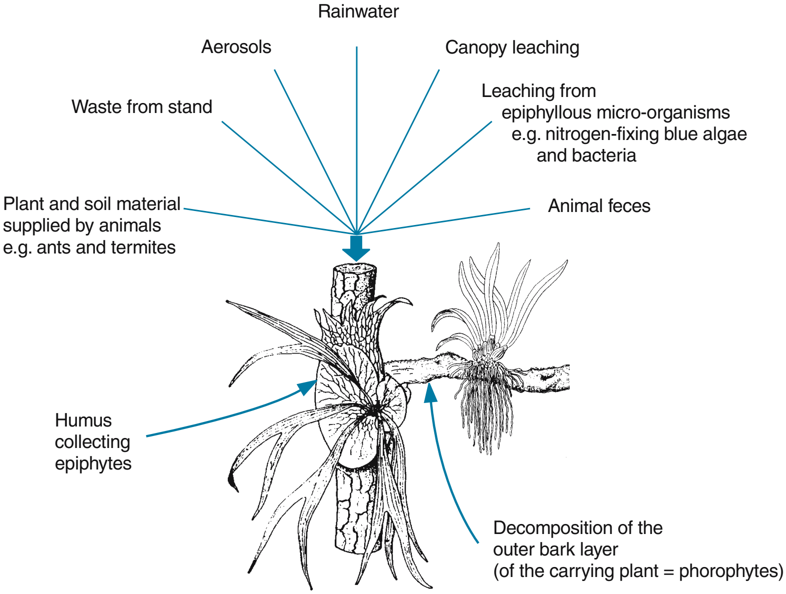


Fig. 15.6. Origin of the root substratum and nutrients for epiphytes.
Source: Johansson 1974

have long pointed drip tips. In Borneo, Sri Lanka and Nigeria, 90% of the tree species have this type of leaf which it is assumed accelerates the runoff of water after rainfall so that the exchanges of gas necessary in photosynthesis and respiration are facilitated.

In the canopy conditions are quite different. Many hours daily of direct solar radiation and exposure to wind can subject the canopy to temporary drought stress. Leaves are xeromorphic, smaller than on species within the forest and leathery. Transpiration is slowed by a wax layer on the leaves and thick cuticles

The growing points for leaves and blossoms are not protected and bud scales are absent, at least on leaf buds. Protection has not been developed against cold or heat as in other ecozones. Where there is protection it is to prevent animals feeding on the buds.

In a large number of species of trees, the shoots and leaves grow rapidly, up to 20 to 30 cm a day. This is possible because hardly any structural tissue and chlorophyll are formed. Hanging shoots are, therefore, white or reddish in color initially. Many plants are cauliflorous. The flowers and fruits of these species grow on the main trunks from leafless shoots, for the cocoa tree and jackfruit this growth form is advantageous because of their heavy fruits.

Buttress roots in which the trunk and roots near the soil are enlarged are also characteristic of the rainforest, in some areas up to 40% of the trees have this root form which supports respiration.

Unlike all other ecozones there is no clear periodicity and no conspicuous visible change apparent in the tropical forest during the year, except where there is a short dry period of up to three months. Seasonally related leaf development, flowering, fruiting and leaf drop and also ring development in the trunks are all absent. These processes are, however, not continuous but occur as phases between long rest periods. The development phases occur at different times of the year and rarely coincide with seasonal changes in the climate. The flowering periods of different species are spread throughout the year. Even within the same species or on different branches of a tree, flowering is not simultaneous.

15.5.2
Dynamics of the vegetation

Each rainforest is a mosaic of stands of different ages which have a distinct fauna, flora, structure, available supplies and turnovers (Fig. 15.7). None is in a steady state. New development takes place when old trees have died off and fall so that gaps occur in the forest in which new growth can be established.

15.5.3
Animals

In most tropical rainforests animals are rarely seen and also hardly heard.The total number of species is larger than in any other ecozone although many species are represented only in small numbers and distribute themselves in a wide variety of ecological niches. The number of reptiles and amphibiens which thrive in the optimal conditions of temperature and humidity is particularly high as is the number of invertebrate species. Most animal species live

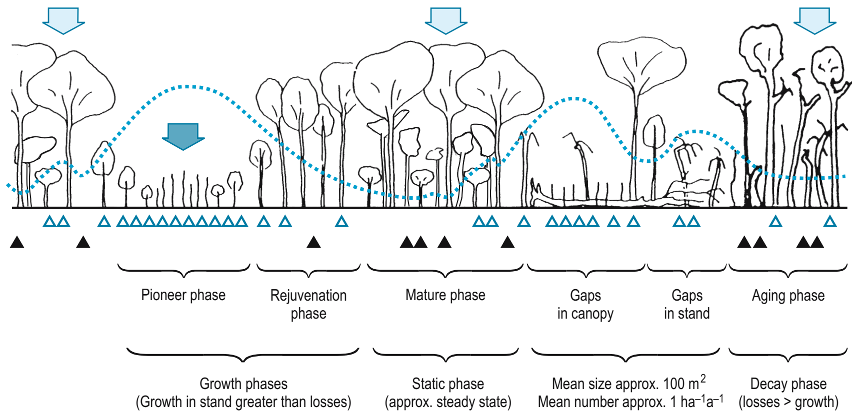


Fig. 15.7. Transect through a rain forest showing stages of maturity of the stand. There are four stages from pioneer to aging. During these phases the mix of species, the relationship of the NPP to waste in the stand and the availability of nutrients in the soil all change. The mature phase in undisturbed forest accounts for about 90% of the total area of the stand. The immature area covers 3–10% and the gaps about 1%. In a stand with different stages of maturity, the light intensity on the forest floor varies (...). The higher light intensity on the ground where there are gaps in the cover favor low growth that requires more light (△△△). Elsewhere the low growth is shade tolerant (▲▲▲). Fruit eating consumers (⇩) dominate in the areas of mature and aging stands. In the pre-mature stands where leaf production predominates, herbivores are more frequent (⬇). Source: after Oldeman 1989

in the higher stories of the forest because the limited plant cover on the forest floor, except in periods of regeneration, provides only enough food for a few herbivores. The variety of animals reflects the size of the available living space and the range of local climates and flora. The great height of many trees extends the potential living area for animals vertically so that there exists a complex three dimensionally structured space in which different animal species can settle in one of the various habitats created. The availability of food and the structure of the living space remains unchanged throughout the year. The food supply, a function of the very large primary production of the tropical rainforest, is exceptionally large.

15.5.4
Biomass and primary production

High solar radiation, equable temperature year-round, high humidity and precipitation distributed throughout the year provide a basis for forest growth in the tropical rainforest, a large *biomass* and high *primary production*, despite the widespread limited soil fertility.

Estimates and measurements of the biomass are available from a great many forests. Most range from 300 t to 650 t ha^{-1}. From 75 to 90% of the biomass is above ground and of this, 90% is in the form of wood in living trees, The leaf mass is about 2%, in absolute amount more than in any other ecozone.

Primary production also exceeds that of any other ecozone. Estimates based on climatic parameters and partial measurements of other components such as the litter, have given values that range from 20 to 30 $t\,ha^{-1}\,a^{-1}$. The highest productivity occurs during the rejuvenation phases. Most plants produce only at certain periods of the year, despite conditions that are suitable year-round for primary production. Nevertheless the periods of production are longer than in all other ecozones which may explain the higher production levels of the tropical rainforest.

15.5.5 Animal feed

Because of the great variety of species but relatively low densities of animals, food chains and webs are very complicated. Many animals are difficult to find and knowledge is limited to all but a few animal species or groups. The *zoomass* is very small and the importance, quantitatively, of the consumption on the turnover of energy and matter in the rainforest ecosystem must also be small and characterized by a short cycle between producers and decomposers with almost no intervention from herbivores. It has been suggested that animals in the rainforest have more of a regulatory role on supplies and processes in the forest system than any immediate effect on the turnover.

15.5.6 Litter, the litter layer, decomposition and humus

Since losses from animal feeding are unimportant, the long term delivery of *litter* in the tropical rainforest is about the same as the above ground net primary production, probably between 15 and 25 $t\,ha^{-1}\,a^{-1}$, of which about 5 to 10 $t\,ha^{-1}\,a^{-1}$ is from leaf fall, 80% of the total leaf mass. This is the proportion of leaves renewed each year. The mean life span of the leaves is about 15 months.

Despite the considerable amount of litter supplied, the forest floor is not usually covered by a closed litter layer. The carbon content of the litter is only 1% of the total organic carbon found in the forest ecosystem, compared to 10% in the deciduous forests of the Temperate midlatitudes. The litter mass is so low because the biological and chemical *decomposition* of organic matter in the continuously warm humid conditions that prevail in the trunk area and on the forest floor is very rapid. Leaf litter can be decomposed within a few months (Table 5.3). Depending on the thickness, dead tree wood is completely decomposed in a few, at most, 15 years.

Humus content is therefore low. In the upper soil it is usually between 1 and 3%, 50 to 150 $t\,ha^{-1}$, less than in the soils under temperate forests. Fungi, termites and earthworms are all involved in the decomposition process. The decomposition by bactaria can be limited in acid soils. Many fungi are mycorrhiza and live in symbiosis with higher plants. Termites take care of the

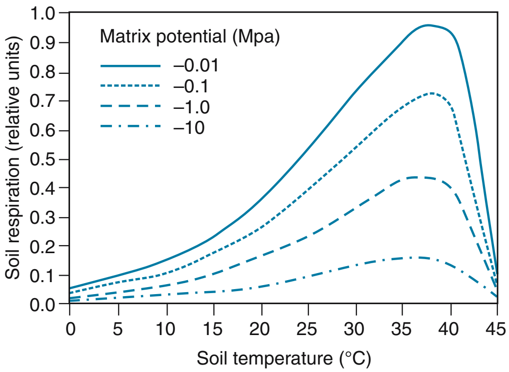


Fig. 15.8. The interdependence of the rate of decomposition (soil respiration), soil temperature and soil moisture. Higher temperatures, particularly in relation to a higher moisture content, and therefore matrix potential, have an accelerating effect on decomposition. Source: Scholes et al.

decomposition of dead wood. The earthworm zoomass is the largest of the decomposers.

15.5.7
Mineral supplies and turnovers

The absolute amount of minerals both in total and for individual minerals per spatial unit are greater and the flows of minerals per time unit and area are higher in the tropical rainforests than in any other forest area. Within the rainforest, the highest values are on soils that are both well supplied with minerals and where concentrations of minerals in the biomass are also larger.

The distribution of the most important mineral supplies and turnovers is shown in Fig. 15.9. It has been suggested that most of the minerals circulating in the rainforest system were in the biomass and not in the soil, as is the case in temperate woodland. Research indicates that this is true only for locations that are very poor in nutrients.

The ability of the rainforest system to keep losses through leaching small is largely the result of the dense root systems in the upper soil, sometimes with roots spread over the soil surface in contact with the litter and also their connection to the mycorrhiza mycelium. In this way, not only the nutrient elements brought in by the precipitation, canopy leaching and stem flow, but also the nutrients in the organic waste are intercepted and supplied to the tree roots directly. Leaching losses that do occur are compensated for by external inputs from precipitation (Table 15.2).

Minerals from the biomass are returned by means of the waste production and canopy leaching. Fire is unimportant. Leaf litter is particularly important in the return of minerals. Although at most half the supply of litter is from leaves, their share of minerals in the litter is far higher than that provided by

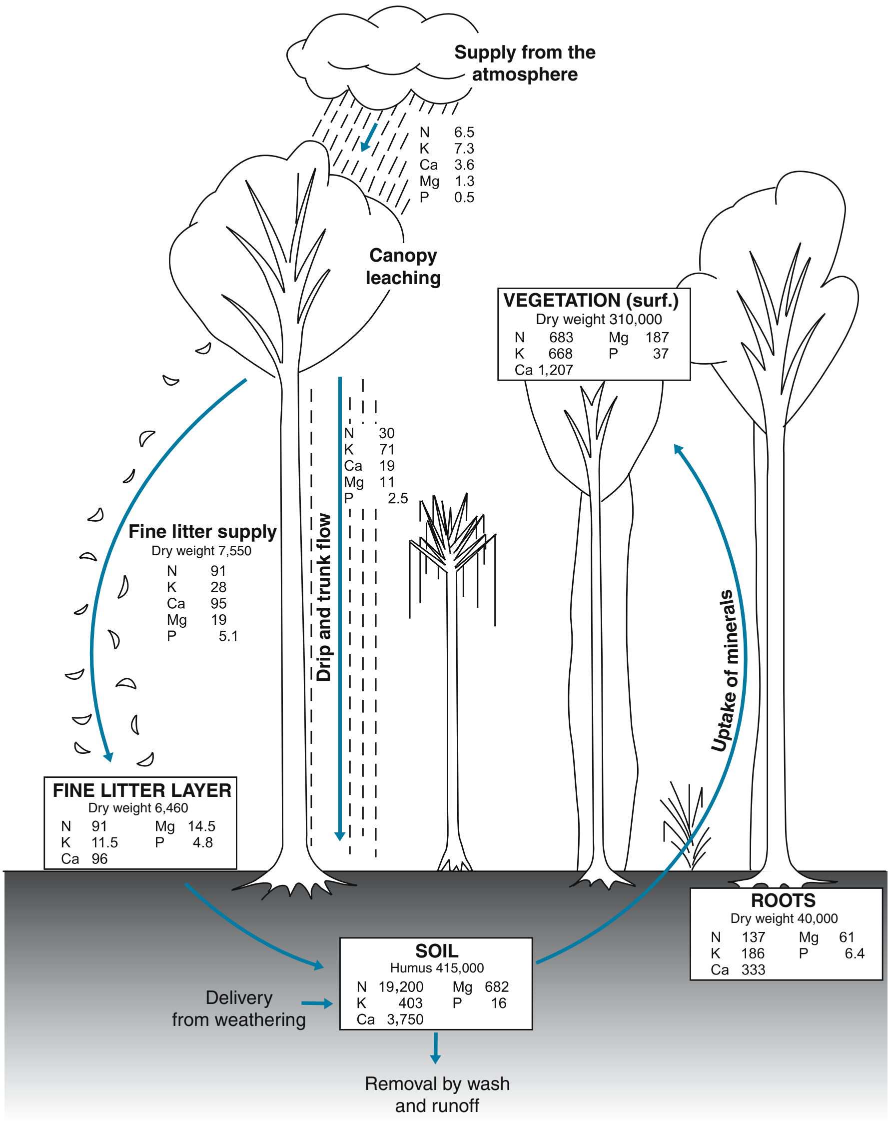


Fig. 15.9. Mineral supply and turnover in an upland rain forest in New Guinea. Supply = $kg\,ha^{-1}$ Turnover $kg\,ha^{-1}\,a^{-1}$. The relatively rich nutrient supply in and on the soil is related to the high humus content of upland forests where the weight of dead organic soil matter may be greater than the biomass weight. The proportion of minerals in the above and below ground biomass is 29% for calcium and 26% for magnesium, less than half of the content for these minerals in the forest system as a whole, including the soil. The proportion of potassium and phosphorous bound in the biomass is 67% and 68% respectively. Source: Edwards 1982

Table 15.2. Minerals supplied to the soil from rainfall, canopy leaching (drip and stem flow) and litter fall in areas of two tropical rainforests in the Ivory Coast

Research area	Mineral supply to soil	N	K	Ca	Mg	P
Plateau	Total ($kg\,ha^{-1}\,a^{-1}$)	258	85	97	91	9.8
	from (%)					
	– rainfall	9	6	22	4	14
	– canopy leaching	25	61	15	40	4
	– litter fall	66	33	63	56	82
Valley	Total ($kg\,ha^{-1}\,a^{-1}$)	246	264	135	90	24
	from (%)					
	– rainfall	10	2	16	4	6
	– canopy leaching	26	67	21	56	38
	– litter fall	64	31	63	40	56

Source: Bernhard-Reversat 1975

fallen branches and trunks, despite loss from the leaves through leaching and the translocation of nutrient elements into the shoots before leaf drop.

Canopy leaching is of particular importance for potassium supplies. Often more than twice as much potassium is returned to the soil in this way than from litter fall. Potassium, therefore, circulates much faster than calcium for example. The canopy also returns a larger proportion of magnesium and phosphorous. For all other nutrient elements, including nitrogen and calcium, the litter fall is much more important (Table 15.2).

The concept that the mineral turnover in the rainforest ecosystem is a closed system of circulation is only partially correct (Fig. 15.10). The tropical rainforests do, however, have a particularly efficient mechanism to obtain their mineral supplies, indicated by the lack of soluble or suspended load in the streams and also by the fact that soil fertility after forest clearing, and therefore stopping of the return flows, declines rapidly.

15.5.8 Rainforest ecosystem

Figure 15.11 shows the typical available supplies and turnovers in a tropical rainforest system. Characteristic are the great diversity of species and the constant external conditions and internal processes in the system. This means that the accumulation of litter and its decomposition, the translocation of minerals from the leaves before leaf drop and the uptake of minerals by the vegetation from the soil are continuous and optimally synchronized during the entire year. In this way, the system is protected from nutrient shortages and leaching. Agricultural use destroys this balance.

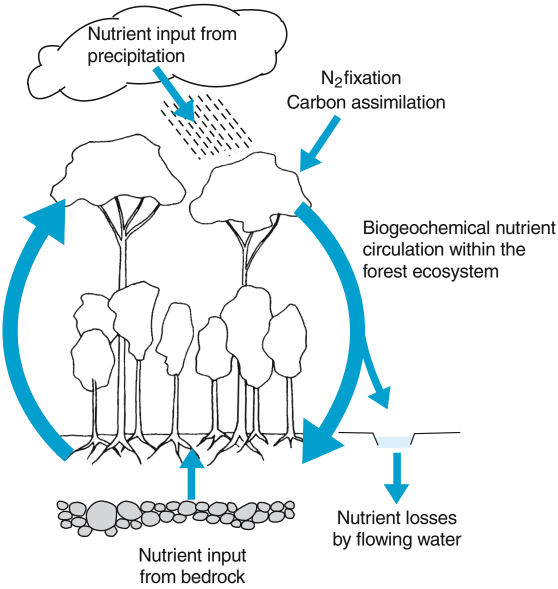


Fig. 15.10. Nutrient supply in a forest ecosytem. Material flows are also received from precipitation and from the bedrock, including seepage and flowing water. Gases are also supplied to the system from nitorgen fixation (N_2) and photosynthesis (carbon dioxide) as well as by the release of nitrogen and phosphorus as a result of decomposition and fire. The amounts supplied from external (thin arrows) are less than those circulating within the system (thick arrows) but are important for the nutrient budget in the forest

15.6 Land use

The tropical rainforests are one of the two remaining forest areas in the world in which agricultural development is still largely limited to areas on the margin of the forest or to island like developments in its interior. The other is the boreal forest (Fig. 6.2). Nevertheless once clearing has begun, these areas increase rapidly in size, as either cutting for timber or for cultivation spread. Fire is also used as a means to clear the forest for agricultural use.

Poor soil quality has limited cultivation in many areas leaving these regions thinly settled (Table 15.3). In general, only *shifting cultivation* is possible if traditional methods are used. Crops such as cassava, taro and yams are grown for a few years in the clearings until a new clearing is prepared by burning the felled branches of trees with their foliage, seldom the tree itself, which provide fertilizer in the form of ash. Harvests in the clearings decline after a few years. Once burnt over, a period of 15 to 30 years is required before a clearing can be successfully cultivated again. Very large areas of land are consumed by this method of agricultural production. Settlements are moved after an even longer

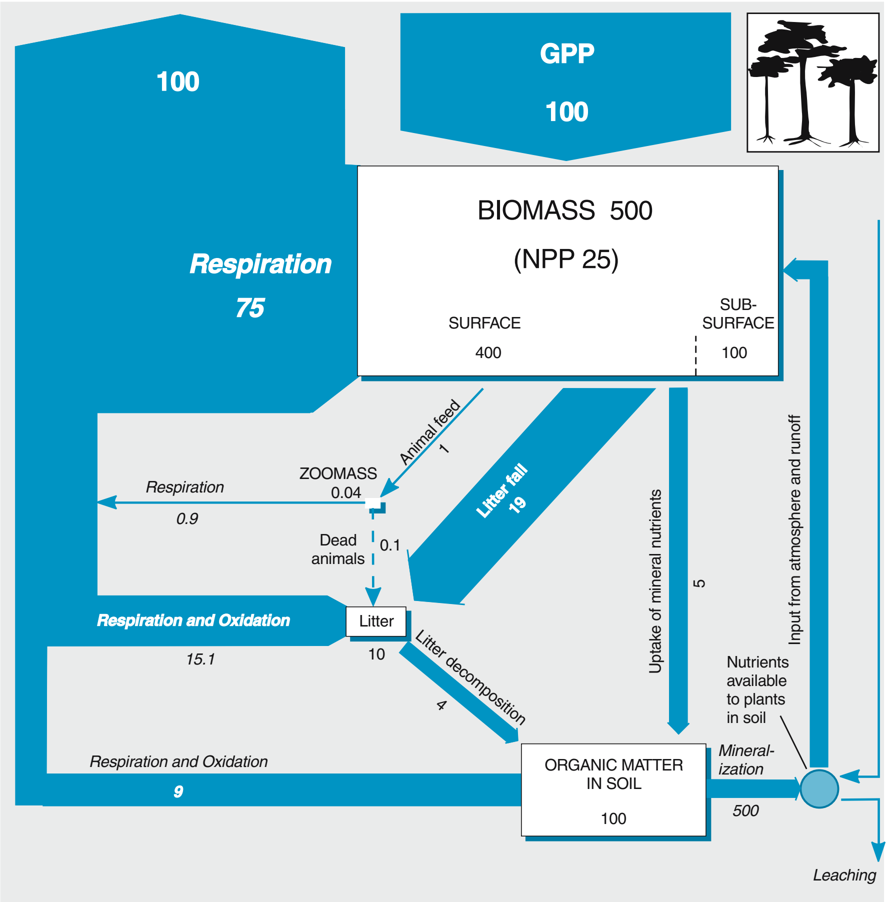


Fig. 15.11. Model of ecosystem of a tropical rain forest. Compared to other zones, the tropical rain forests have 1. a larger biomass and smaller supply of litter and organic matter in the soil, 2. a high turnover rate of energy and minerals and 3. in poor locations, low quantities of exchangeable nutrient elements in the soil. Width of arrows, areas of circle and boxes are approximately in proportion to the volumes involved. Organic substances in ha^{-1} or $ha^{-1}\,a^{-1}$, minerals in $kg\,ha^{-1}\,a^{-1}$

period when the distance to the new clearing becomes too great. The migration of the families takes place within traditionally defined forest areas.

The decline in productivity the longer an area is cultivated was thought to be caused by a decline in nutrients because of the uptake by the crops and to soil leaching. Research in a tropical forest in southern Venezuela near San Carlos de Rio Negro, indicates, however, that supplies of the most important minerals in the soil do not decline during the normal three year cultivation of an area with manioc (Jordan 1987). It was found that output is reduced, for example,

Table 15.3. Distribution of disadvantageous soil properties in the tropics with year-round rain and the tropics with seasonal rain

Disadvantageous soil characteristics	Humid tropics[f/]		Moist savanna		Dry and thorn savanna	
	10^6 ha	%	10^6 ha	%	10^6 ha	%
Low mineral nutrient content[a/]	929	(64)	287	(55)	166	(16)
Aluminum toxicity[b/]	808	(56)	261	(50)	132	(13)
Acidity without Al toxicity[c/]	257	(18)	264	(50)	298	(29)
High phosphate fixation[d/]	537	(37)	166	(32)	94	(9)
Low cation exchange capacity[e/]	165	(11)	19	(4)	63	(6)
Total area	1444	(100)	525	(100)	1012	(100)

a/ < 10% of usable minerals in the silt and sand fractions
b/ > 60% of the Al saturation in the upper soil layer (1–50 cm)
c/ pH < 5 (low base saturation)
d/ only in soils with high clay content, absent in sandy and loamy Acrisols and Ferralsols
e/ CEC_{eff} < 4 cmol(+)kg^{-1} (with a pH value of 7, this corresponds to 7 cmol(+)kg^{-1}). Soils are liable for leaching (which takes place most frequently in Arenosols, Podzols and Acrisols).
f/ The humid tropics cover almost the same area as the Tropics with year-round rain ecozone.

The total area of soils with disdvantageous soil characteristics is highest in the Tropics with year-round rain and next highest in the moist savanna of the Tropics with summer rain. Individual characteristics are, however, frequently interrelated and occur together in many Arenosols, Podzols, Acrisols and Ferralsols, for example, so that even in the humid tropics there are considerable areas of soils without any of these five disadvantageous characteristics.
Source: Sanchez and Logan 1992

if there is an increase in the fixation of phosphates and in aluminum toxicity, both of which increasingly affect plants. An initial rise in the *pH value* from 3.9 to 5.4, which followed the burning of an area and its fertilization with ash, was paralleled by an increase in the available phophates and reduction in toxic aluminum. When the land was cultivated the pH values soon declined to 4.1 and later 3.8 and with this decline phosphate fixation and aluminium toxicity rose again to former high levels. This indicates that the benefit of burning off the land lies in the increase in pH, rather than the release of plant nutrients (Fig. 15.12).

Ecologically, slash and burn cultivation has been a sound system. Yields, even when only for a family's subsistence, are, however, small in relation to the high input of labor. Eventually also, the time span available between the phases of cultivation is too short for the forest to regenerate. This occurs already at a population density of 6 per square kilometer because the area required by a family is very large, with a factor of 10 to 15 (Chap. 14.6).

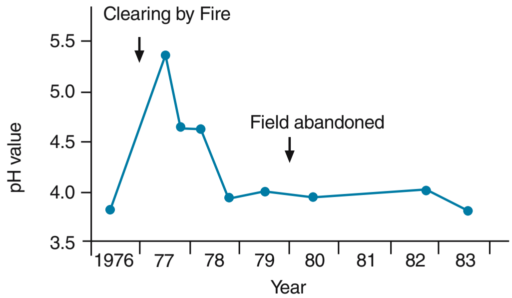


Fig. 15.12. Changes in the pH values in the soil in an Amazonian rain forest after clearing by fire, followed by a three year period of traditional shifting cultivation. Source: Jordan 1987

Slash and burn cultivation can be replaced by modern farming methods. The level of plant nutrients in the soil after clearing is moderately high. Also, the initial decline in humus after clearing levels off and, depending on the type of cultivation or degree of forest regeneration, may even increase again. With the addition of organic matter to the soil in the form of mulch and of lime to raise the pH value, the cation exchange capacity increases. Toxic aluminum is also removed and the availability of phosphates improves. High yields have been achieved in several areas of the humid tropics after the introduction of suitable forms of land use and cultivation, indicating that long term success using such methods is possible.

In Yurimaguas, for example, in Peru in the western Amazon basin the soil is a sandy Acrisol with a high aluminum content and shortages of phosphorous and potassium and most other nutrient elements, together with a pH value of a little over 4. Mean annual precipitation is 2,200 mm. With the addition of fertilizer and lime at a rate of 3 t ha^{-1} every three years and suitable rotation

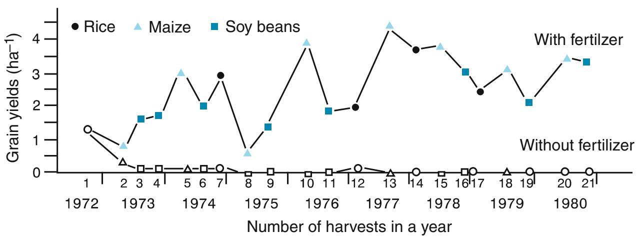


Fig. 15.13. Development of yields on permanently cultivated fields on an Amazonian Acrisol in Yurimaguas, Peru. The upper curve shows yields using fertilizers (initially 80-100-80 kg N-P-K per hectare and later, when the pH reaches 5.5, of 100-26-80 kg N-P-K per hectare and root crop) together with a crop rotation of hill rice, maize and soy beans. In most years two crops were grown, in some three. After 25 harvests the mean yield was 7.8*t* ha^{-1} a^{-1}. Yields did not decrease during the period, in contrast to yields where no fertilizer was applied. After three harvests, yields were almost zero. Source: Jordan 1987, Bandy and Sanchez 1986

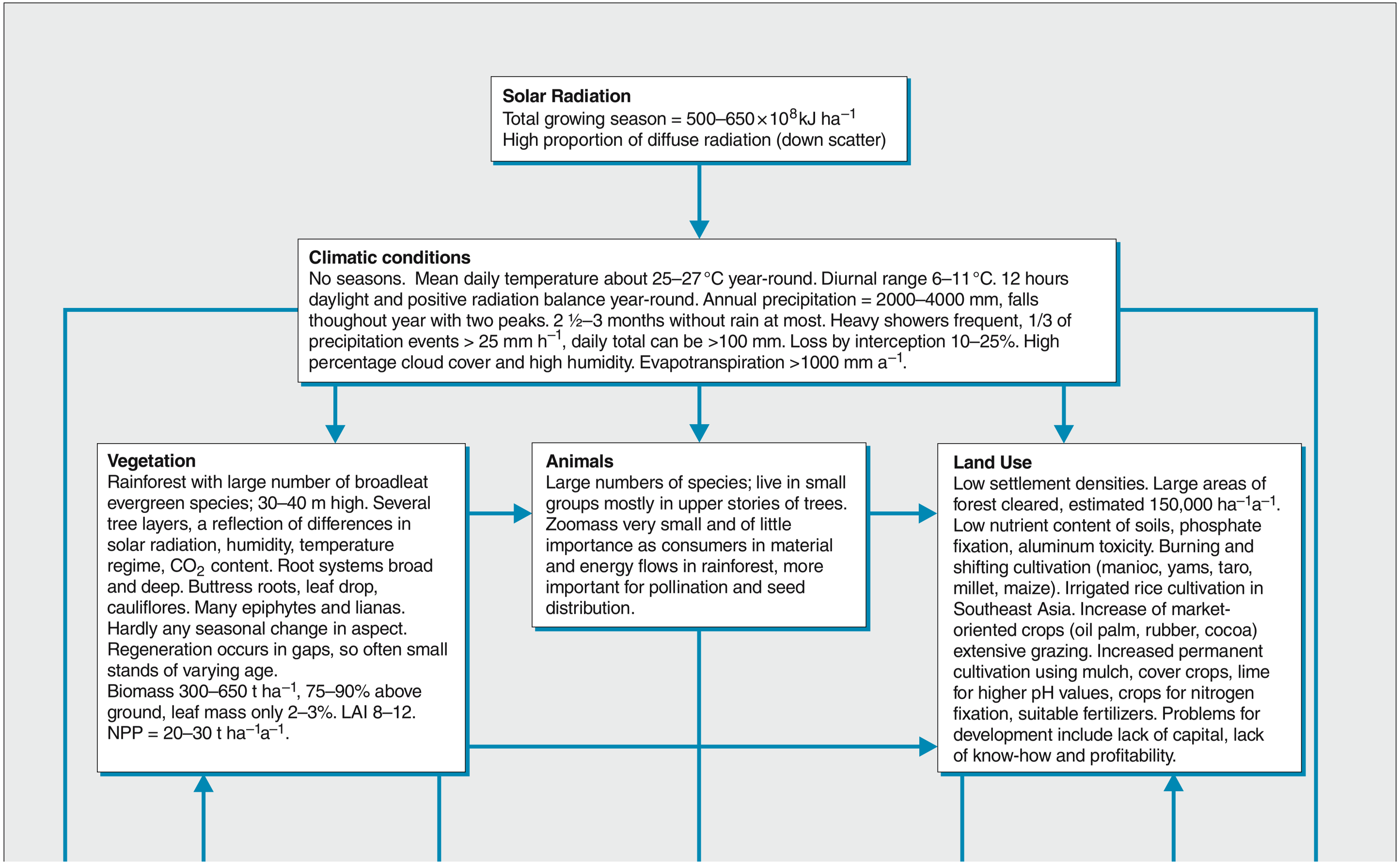
of crops, the nutrient content of the soil and the pH value were considerably increased and aluminum content decreased, so that high yields could be maintained (Fig. 15.13).

A large share of the cultivated area in the ecozone is taken up by *tree crops*, more than in any other ecozone. Production is from both small and middle-sized family holdings with several different crops and from large scale *plantations* which tend to specialize on one crop (monoculture). Many plantations process their crop on the plantation, often for the export market, bringing in labor from outside so that income levels are generally higher. Also characteristic of plantations are high capital investment requirements per spatial unit and a dependence on world markets. Their risk is that they have a low production flexibility, especially if trees are grown which take a long time to mature.

The trees, shrubs or lianas in the tropics include rubber, oil and coconut palm, cocoa, spices such as pepper, cinnamon, vanilla, nutmeg, cloves and allspice, as well as coffee and tea. Pineapple and sugar cane are grown in large plantations as field crops and cassava on small farms.

Considerable areas of former forests, especially in South America have been developed as large scale *cattle grazing* enterprises in recent years. These are now, spatially, the largest form of land use in many areas.

The tropics are still cultivated for the most part using traditional farming methods, despite the natural potential of these areas. Lack of capital to invest in the land and a lack of knowledge are the main causes preventing the use of more modern methods. In many cases, the introduction of new forms of cultivation are frustrated because the increased production costs resulting from the purchase of seeds, pecticides and fertilizer necessary for the introduction and maintenance of new forms of cultivation are not covered by an increase in income or profitability.


Solar Radiation
Total growing season = 500–650 × 10⁸ kJ ha⁻¹
High proportion of diffuse radiation (down scatter)
Climatic conditions
No seasons. Mean daily temperature about 25–27 °C year-round. Diurnal range 6–11 °C. 12 hours daylight and positive radiation balance year-round. Annual precipitation = 2000–4000 mm, falls thoughout year with two peaks. 2 ½–3 months without rain at most. Heavy showers frequent, 1/3 of precipitation events > 25 mm h⁻¹, daily total can be >100 mm. Loss by interception 10–25%. High percentage cloud cover and high humidity. Evapotranspiration >1000 mm a⁻¹.
Vegetation
Rainforest with large number of broadleat evergreen species; 30–40 m high. Several tree layers, a reflection of differences in solar radiation, humidity, temperature regime, CO2 content. Root systems broad and deep. Buttress roots, leaf drop, cauliflores. Many epiphytes and lianas. Hardly any seasonal change in aspect. Regeneration occurs in gaps, so often small stands of varying age.
Biomass 300–650 t ha⁻¹, 75–90% above ground, leaf mass only 2–3%. LAI 8–12. NPP = 20–30 t ha⁻¹a⁻¹.
Animals
Large numbers of species; live in small groups mostly in upper stories of trees. Zoomass very small and of little importance as consumers in material and energy flows in rainforest, more important for pollination and seed distribution.
Land Use
Low settlement densities. Large areas of forest cleared, estimated 150,000 ha⁻¹a⁻¹. Low nutrient content of soils, phosphate fixation, aluminum toxicity. Burning and shifting cultivation (manioc, yams, taro, millet, maize). Irrigated rice cultivation in Southeast Asia. Increase of market-oriented crops (oil palm, rubber, cocoa) extensive grazing. Increased permanent cultivation using mulch, cover crops, lime for higher pH values, crops for nitrogen fixation, suitable fertilizers. Problems for development include lack of capital, lack of know-how and profitability.

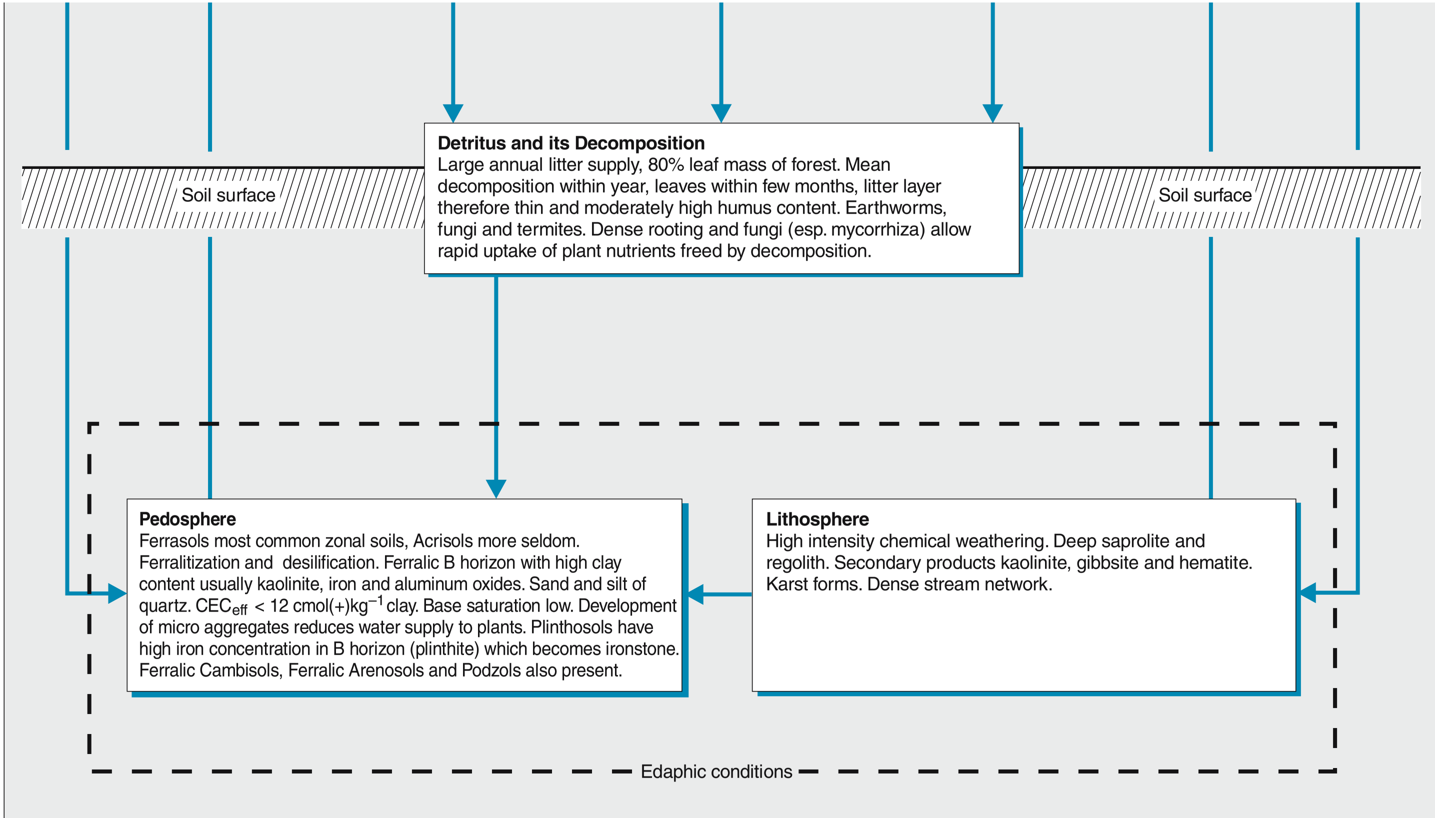


Fig. 15.14. Synoptic diagram for the Tropics with year-round rain