Tropics with summer rain

14.1
Distribution

The Tropics with summer rain lie between the tropical rainforests on the equator and the Dry tropics and subtropics. The boundary of the ecozone towards the arid regions is determined largely by the availability of water. An area is arid if the mean annual precipitation is less than 500 mm, of which nearly all falls in fewer than 5 months (Fig. 14.2). About 25 million km^2 or 16% of the land mass belong to this ecozone.

The main plant formations of the ecozone are various types of *savanna* vegetation. The terms savanna climate or savanna belt are sometimes used to describe the zone as a whole.

The savanna is subdivided into a *dry savanna* and *moist savanna* depending on the total annual precipitation and its duration (Figs. 1.1 and 14.2). The differentiation of vegetation, soils and land use within the savanna is also

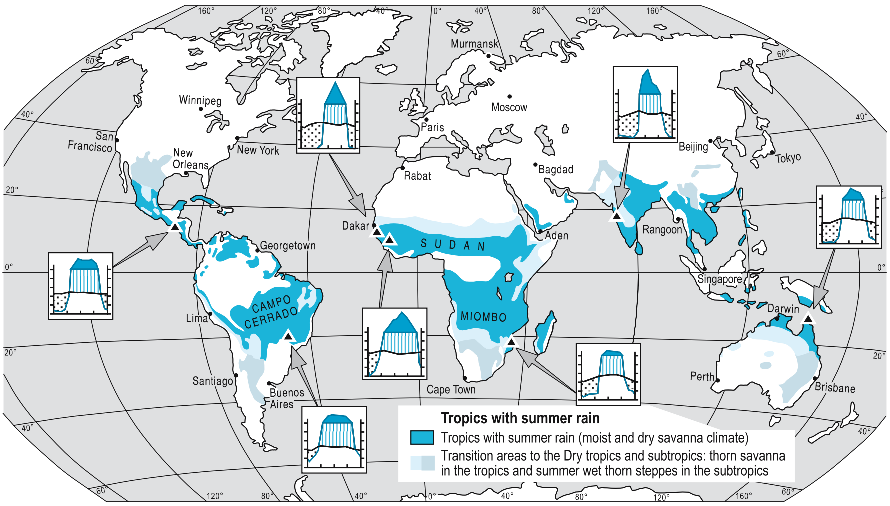


Fig. 14.1. Tropics with summer rain

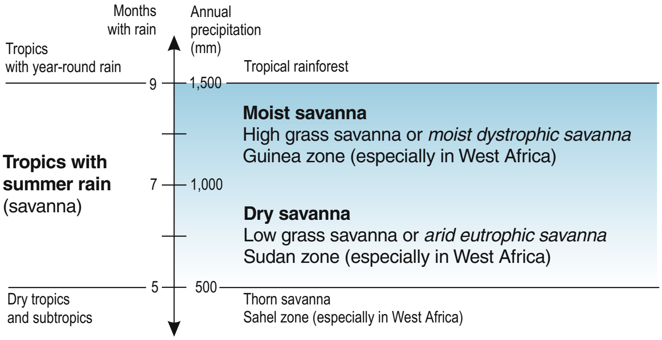


Fig. 14.2. Regional differentiation within the Tropics with summer rain

an expression of this climatic division. Grasslands have a considerably lower growth in the dry savanna, for example, compared to the high grass savanna of the moister areas where tree stands are also denser and higher than in the dry savanna.

Soils in the dry savanna usually have a higher exchange capacity and base saturation and are richer in humus than the moist savannas. The higher soil fertility allows a permanent or at least semi-permanent cultivation.

The soils of the moist savanna are usually developed on deeply weathered bedrock. Decomposition rates of organic detritus are high and leaching is considerable so that the soils are poor in nutrients and humus. Cultivation with periods of fallow and shifting cultivation characterize land use. The limited nutrient supply rather than lack of water determine the productivity of the soils.

The two savanna types are also known as arid eutropic savanna and moist dystrophic savanna, a reflection of the differences in soil fertility.

14.2 Climate

Because of the positive radiation balance throughout the year and small drop in temperature during the rainy season mean temperatures are equable year-round. The mean monthly temperature range is generally less than the diurnal range. In all months the mean is over 18 °C. The highest temperatures occur before the rainy season and the mean monthly maxima may exceed 40 °C at this time. Monthly means and also daily mean temperatures are lowest in the dry season; the minimum daily temperature occurs in the middle of the dry period (Fig. 14.3). Frost is absent during the rainy season but in some upland areas temperatures may fall below freezing in the dry season. The winter dry season lasts from 2.5 to 7.5 months. Annual precipitation ranges from 500–1,500 mm.

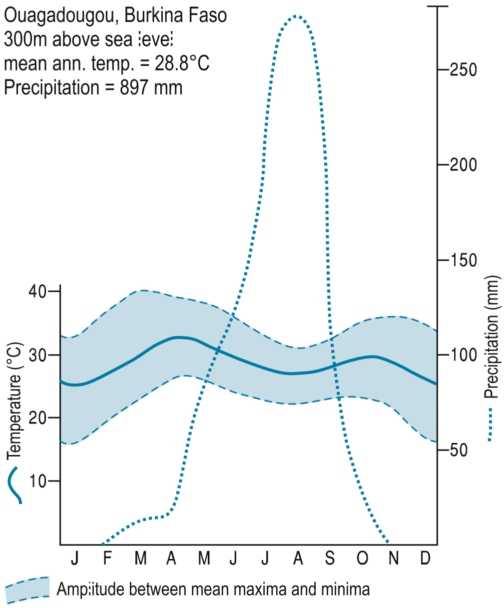


Fig. 14.3. Temperatures in the Tropics with summer rain. An example of dry savanna at Ouagadougou, Burkino Faso. The dip in summer temperatures is caused by the cooling effect of the rainy season. Further north the dip is gradually reduced with the shortening of the rainy season and is not present in the Dry tropics and subtropics. The difference between the mean maxima and the mean minima is 9 °C in the rainy season in this example and 18 °C in the dry season because of the higher solar radiation during daytime and greater losses at night. Source: Müller 1996

14.3 Relief and drainage

Relief in the Tropics with summer rain is characterized by large areas of almost level land surfaces known as *peneplains*. Denudation has removed all differences in bedrock and geological structures and even valley sides have such a low angle that they are hardly visible in the landscape. The peneplains contain broad shallow drainage ways separated by broad, low overland flow divides. The shallow drainage ways, which are at most a few square kilometers in size, frequently serve as valley heads which fill with stagnant water or flood for a short period during the rainy season. In the dry savanna Vertisols are developed in these areas and in the moist savanna, Gleysols. Both are covered with grassland. In Zambia the hollows are known as dambos and in Tanzenia as mbugas.

On the divides and in the valleys *laterite* is often present at or a little below the surface as an irreversably hardened soil horizon of subsoil rich in iron (plinthite). This type of *duricrus*t is termed *ferricrete* and often lies above the surface after wash denudation has removed the material at the surface

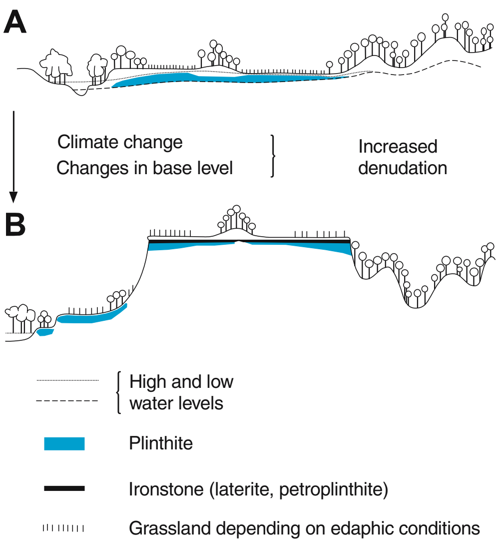


Fig. 14.4. The development of plinthite in areas of stagnant drainage or groundwater influenced surfaces and the irreversible hardening of plinthite to ironstone (laterite and petroplinthite). Plinthite develops when the ground is repeatedly dried out during a period of climate change from year-round rain to seasonal rain or when the base level changes A similiar effect can be created when forests are cleared and the soil dries out because of the increased solar radiation. Wash processes may cause further drying out of the plinthite horizon. Source: Spaargaren and Deckers 1998

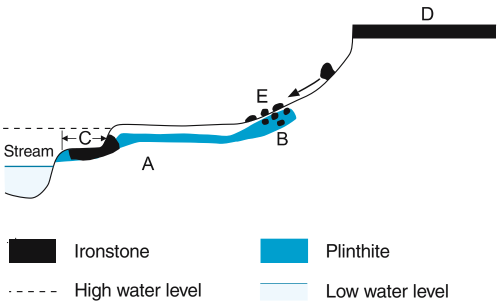


Fig. 14.5. Occurrence of plinthites and ironstone (petroplinthite) under moist tropical conditions in relation to relief. Soft plinthite develops in continuously moist subsurfaces of river terraces and flood plains (A) as well as areas near springs at the foot of uplands and scarps (B). If the plinthite dries out on, for example, river terraces (C) or wash surfaces of upland areas (D), irreversible hardening occurs and petroplinthite is developed in situ. Iron rich debris may accumulate in the colluvium on the foot slopes of uplands and scarps (E). Source: from Driessen and Dudal (1991)

(Fig. 14.4). Duricrusts also cement wash surfaces and form resistant layers in piedmont steps, on upland slopes or river terraces (Fig. 14.5).

During the rainy season much of the precipitation does not infiltrate but reaches the valleys as overland flow. Intense precipitation events are frequent in the tropics, sometimes in association with tropical cyclones and are the main cause, combined with the low *infiltration* capacity of the often, fine grained soils, that underlie the predominance of this process. Where the slope angle is low and the surface relatively smooth, sheet flow occurs, where the slopes are steeper and surfaces rougher, because of either boulders or vegetation, there is rill wash.

Over long periods of time all forms of denudation lead to a continual lowering of the *regolith* cover. The lowering of the underlying bedrock and the development of bas-relief surfaces, the actual peneplain development, occurs in conjunction with the chemical weathering process at the lower boundary of the regolith cover on the bedrock surface. On the land surface, the regolith is removed by wash denudation. The regolith cover advances the weathering process up to a certain depth because moisture in the regolith is stored in contact with the underlying bedrock so that the weathering continues between precipitation events and into the dry season. The lowering at the regolith surface and at the bedrock surface is termed double planation. When the rate of removal at the surface is the same as the rate of regolith production, a dynamic equilibrium exists. The often thick regolith cover in many areas of the tropics indicates, not only that weathering rates have been very high, but also must have been higher than the rates of denudation at the surface.

Rock surfaces in the form of *inselbergs*, *pediments* or piedmonts cover relatively small areas. They occur because the potential denudation has exceeded the ability of the rock to produce weathered material. Inselbergs are often isolated individual or groups of hills rising above a level surface. Their slopes are steep and the change in gradient to the plain often abrupt. Sometimes they are surrounded at the base by low angled pediments.

In some cases inselbergs are the result of tectonic activity, or when resistant rock was surrounded by areas of less resistant rock that was removed; sometimes they are isolated features a relatively large distance from streams or are exposed blocks that were more resistant to weathering at depth, perhaps because they were less jointed. Such blocks now rise above the surface as the weathered material that embedded them has been removed (Fig. 14.6)

Most smaller streams only flow in the rainy season. Stream flow at the beginning of the rainy season is associated with surface runoff from individual events and is therefore episodic with very high peak flows. With the advance of the rainy season flow becomes continuous, particularly as supplies from groundwater reach the stream. As the rainy season ends stream flow declines again to zero.

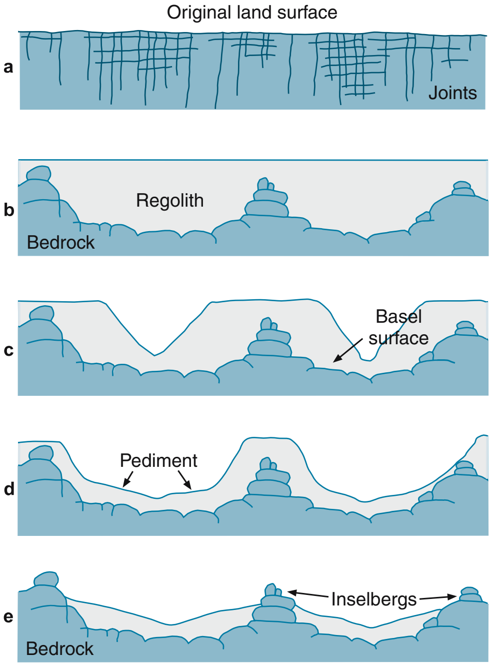


Fig. 14.6. Development of inselbergs. Source: Ollier 1984

14.4 Soils

14.4.1 General characteristics of soils in the subtropics and tropics with summer and year-round rain

The boundary area between the Dry tropics and the subtropics and the Tropics with summer rain is the equatorward limit of *pedocals*. When mean precipitation is above 500 to 600 mm, leaching replaces enrichment and *pedalfers* are the predominant soil type in well drained locations. They are acid and therefore poor in exchangeable nutrient ions. Free carbonates and salt are absent and the displacement of clay from the upper to the lower soil layers is widespread.

The pedalfers of the tropics differ from those in higher latitudes largely because of the warm moist climatic conditions and intensive chemical weathering. Characteristic for the tropics are two layer clay minerals, usually kaolinite, sometimes also halloysite. Sesquioxides are frequent, increasing with the intensity and duration of the warm wet conditions, reaching their maximum where silicium is released as a consequence of weathering. Hematites in particular develop following oxidation of the iron that is in many rock minerals, giving the soil a reddish color. There are few weatherable silicates in these soils. In extreme cases the delivery of mineral nutrients is almost entirely the result

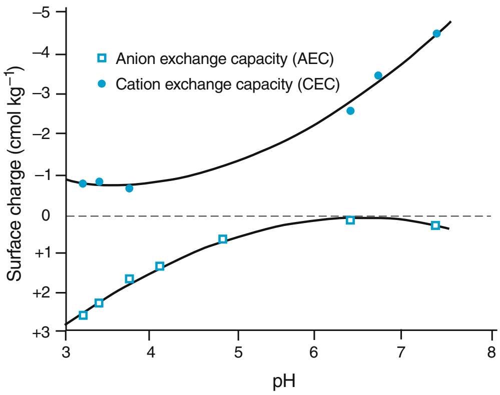


Fig. 14.7. The dependence of pH on the charging characteristics (anion and cation exchange capacity) in low activity clays in a ferralic B horizon (Ferrasol). Source: from Van Wambeke 1992

Table 14.1. Comparison of properties of selected soil types in the Subtropics and tropics with summer rain and the Subtropics and tropics with year-round rain

Soil type	CEC (cmol(+) kg^{-1} clay)	Base saturation (%)	Illuviation of clay in B horizon	Characteristics
Lixisols	< 24	≥ 50	argic horizon	unstable soil structure
Acrisols	< 24	< 50	argic horizon	unstable soil structure
Alisols	≥ 24	< 50	argic horizon	high Al content
Nitisols	< 24	±50	partial (nitic hor.)	favorable soil structure
Ferralsols	≤ 16	< 50	ferralic horizon (no enrichment)	micro sand aggregates
Plinthosols	< 16	< 50	plinthic horizon (no enrichment)	B horizon rich in iron, laterite development can occur

of decomposition of plant detritus and inputs from the atmosphere, both of which are concentrated in the uppermost soil layers.

All important zonal soils in the subtropics and tropics with high rainfall are low activity clay soils with a cation exchange capacity of less than 24 cmol(+) kg^{-1} clay, they include Ferralsols, Plinthosols, Acrisols, and Lixisols. Nitisols are a border case (Table 14.1). The exchange capacities of low activity clays are more dependent on pH than high activity clays. In kaolinites, the surplus of negative charges increases with increasing pH, so the CEC increases also. On the other hand, the positive surplus charges in sesquioxides increase with declining pH, so that the AEC increases (Fig. 14.7).

One consequence of this is that in acid soils rich in sesquioxides, especially Acrisols and Ferralsols, the adsorption of phosphorous anions (PO_4), can be

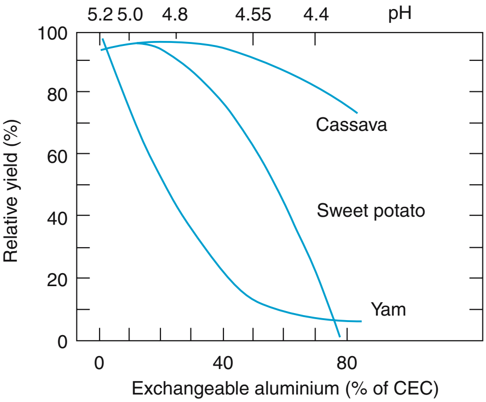


Fig. 14.8. Relationship between exchangeable aluminum, pH in the soil and yield of three tropical cultivated tubers. Source: Norman et al. 1995, Marschner 1990

irreversable and the phosphorous is fixed in the soil as iron phosphate and aluminum phosphate, creating very negative conditions for cultivation. Also, with increasing acidity, from about pH 5, the aluminum compounds tend to be dissolved and the aluminum solution in the soil can reach a saturation level that is toxic to plants, defined usually as a level above 60%. The tropical crop most affected by *aluminum toxicity* is the yam, sweet potatos less so and cassava least of all (Fig. 14.8).

pH values can be improved by liming the soil which may also lead to an increase of up to 50% in the CEC. The disadvantages of phospate fixing and aluminum toxicity are reduced in this way or even disappear and the effectiveness of fertilization is greatly enhanced.

14.4.2 Soil types

Lixisols, Nitisols and Vertisols are the most common soils in the Tropics with summer rain. Other soils in the ecozone are discussed in the relevant chapters, Acrisols and Alisols in Chap. 12.4, and Ferralsols and Plinthosols in Chap. 15.4.

Lixisols formerly belonged to the soil group known as Luvisols. They are soils with a low CEC, in the B horizon sometimes less than 24 cmol(+) kg^{-1}. They also develop an argic B horizon and have a base saturation of at least 50%. The pH values and the quantity of exchangeable nutrient ions are higher than in Acrisols and Ferralsols. The yield potential is moderately high, despite low humus content and low activity clays. Lixisols are, however, vulnerable to soil erosion. After heavy rain the soil surface silts up and once dried out, crusts may form If heavy machinery or plows are introduced, the unstable soil structure is likely to be disturbed.

Nitisols are developed on silicate rich rocks such as basalt or schist and are relatively young. There are always remains of weathered materials in silt and sand grain sizes in the soils. The Nitisols are defined by a nitic horizon which has a stable structure and angular blocky aggregates with shiny surfaces. Although Nitisols have a high clay content (mainly kaolinite and sesquioxides) porosity is high enough for precipitation to infiltrate rapidly. A large amount of bound water can therefore be stored and the soil is well aerated. Nitisols are not greatly affected by soil erosion and have a high usable field capacity. Ecologically they are some of the best soils in the tropics and subtropics and traditionally have been cultivated permanently without fallow. Reddish to dark brown in color, they occur in isolated pockets and account for perhaps a fifth of the area within the more widespread Acrisols and Lixisols.

Vertisols are dark grey to black in color, except for the brown chromic Vertisols. Clay content is high, at least 30%, frequently more than 50%. Vertisols are one of the frequently occurring soils in the subtropics and tropics where there are from 3 to 9 dry months and at least 200 to 300 mm mean annual precipitation. They are developed on formerly grass covered level or gently inclined land surfaces and in poorly drained hollows on weathering products that have a high clay content containing primarily $CaCO_3$ and on sediments. In the rainy season, Vertisols have a sticky and plastic consistency but harden during the dry season that follows. Fissures and cracks form in the hardened surface that are from 1 to 10 cm in width and up to 150 cm in depth and which divide the soil mass into polyhedrons. The cracks become filled with soil material loosened and trampled in by animals or washed in during the first precipitation event after the dry season. In this way, the dry volume of the soil is increased and when subsequently wetted the soil swells causing pressure locally, at least in the subsurface. Movements within the soil follow during which the soil mass is homogenized and mixed. The development of an Ah horizon more than 1 meter in depth often results.

Movement is the defining characteristic of Vertisols. Within the soils, there are shear surfaces, slickensides, on which the clay minerals' surfaces lie parallel to one another and along which shearing takes place. At the surface, gilgai, a microrelief of small mounds and depressions, increase the possibility of movement in the soil because the distribution of preciptation on the surface leads to a small scale variation in the wetting of the soil. (Former names for Vertisols include regur and black cotton soils) (Fig. 14.9).

The high content of clay minerals in Vertisols, in particular smectite, underlies the swelling and shrinking and subsequent movement in the soil as the water content of the soil changes. The cation exchange capacity of 40 to 80 of the Vertisols is high and they are neutral to alkaline. Carbonates may be precipitated out, partly as concretions. Humus content is less than 3%, the humus material is in stable humus complexes and the carbon nitrogen ratio around 15.

The high nutrient content of Vertisols gives them a high production potential which, however, is limited by the problems created by the clay content. For example, the plants have a high wilting point because only a small proportion of the water stored in the soil can be used in the plants. Also losses from

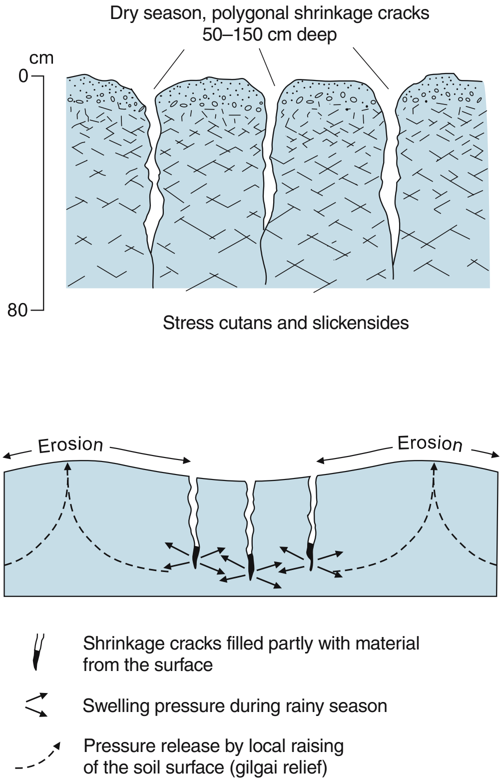


Fig. 14.9. Self-mulching and gilgai (micro) relief develoment in Vertisols. Source Driessen and Dudal 1991

evaporation are relatively high, in part because of capillary movement in the soil. Movement in the soil, in general, can affect root systems detrimentally. Moreover the soil is vulnerable to soil erosion and difficult to work because it is heavy and sticky when wet and very hard when dried out. Most Vertisols are used for pasture, either natural or semi-natural. Cotton, sugar cane, wheat and sorghum are cultivated but have to be irrigated.

14.5 Vegetation and animals

14.5.1 Structural characteristics of savanna vegetation

Savanna vegetation includes tree savannas, shrub savannas and grass savannas. The grass cover is uninterrupted but tree densities range from almost treeless areas to almost closed canopies. In most cases, the clearings are the result of fire, grazing or wood cutting and not related to the location. Studies in areas unaffected by human intervention indicate that the density, height and number of species increase in relation to the length of the period of non-intervention. It is likely that in the area of the moist savanna closed stands of trees originally covered far larger areas than at the present time. The grassland that dominates now is probably often a secondary vegetation.

The densities and heights of the trees are lower on soils with a high nutrient content in the dry regions of the savanna, the *arid eutropic savanna*, than in areas of greater moisture with soils having a low nutrient content, the *moist dystropic savannas* (Huntley and Walker 1982, Cole 1986).

Grass heights also vary. Grasses in the moist savanna reach more than 1 meter, sometimes even more than 2. In the dryer areas, the grasses are less than 80 cm high, but taller than the steppe grasslands in cooler climates.

The three to seven arid months are the most important factor in limiting plant growth. During the dry season, many tree species drop their leaves and the shoots of the perennial grasses and other herbaceous plants die off. The litter produced protects the growth point of the plants until the growth begins again in the following season In this way the photosynthesis decreases to zero or a little above for several months, similar to plants in the Temperate midlatitudes where activity is reduced in winter because of cold rather than the aridity.

When and for how long a tree in the savanna loses its leaves depends on the species and particular environment of the tree. Usually the *leaf drop* occurs several weeks after the herbaceous plants wither. If the water supply in individual years remains within the root area of the tree, the leaves do not fall in that year. The storage of water in most loamy soils is about 15–20% of the soil volume, 15 to 20 mm for each 10 cm in depth or 15 to 20 litres per square meter. The depth of storage depends on the amount of water surplus from the previous rainy season. The higher the surplus, the longer the growing period in any one year.

The leaves also change color before they fall, although with much less variation than in the deciduous trees of the midlatitudes. Many trees and shrubs bloom in the month before the rainy season begins.

14.5.2 Animals

Characteristic for the savanna is the wide range of insect life and spiders. Locusts, grasshoppers, roaches, hemipterans, beetles, flies, mosquitos, butterflies, bees, wasps, ants and *termites* are present in large numbers.

Termite hills range from less than one meter in height to 5 or 6 meters; they have a narrow or broad form and stand either singly or in dense groups covering up to 5% of an area. They are noticeable in the landscape not only because of their appearance but because vegetation near the termite hills differs from that in the surrounding areas. Tree and shrub cover is denser and the herbaceous and grass flora is not the same as elsewhere, such areas are sometimes described as termite savanna.

Among the large numbers of vertebrate species in the ecozone are the four main groups of reptiles, snakes, lizards, crocodiles and tortoises, all but the latter are carnivores. There are also large numbers of running birds, such as ostrich, nandus and emus and bustards as well as ground nesting birds and various birds of prey. Of the mammals, rodents, rabbits and hares are common in all areas.

The development of species on each continents has varied greatly. Not only do the groups of animals differ because of the environmental differentiation in the savanna in different parts of the world, but also because of the numbers of animals, the zoomass, and their growth form and function in the ecosystem. Many of the African savannas have a unique and greatly varied animal life.

14.5.3 Savanna fires

Few areas of the savanna have escaped *fires*. Caused for the most part by man, they usually occur in the dry season and accentuate the normal seasonality of the area. Fires can be advantageous or destructive in their effects. In an area immediately affected, fire is an important selection factor for fauna and flora. Fire also determines the vegetation structure, the tree cover for example, influences the heat and water budget of the soil, the plant cover and the air layer near the soil, as well as changes in the supply of materials and energy and turnover in the system, including the volume of above ground biomass and litter, turnover by herbivores and saprophytes, together with the recycling of minerals.

In general the annual emissions of nitric oxide (NO_2) ammonia (NH_3) and carbon dioxide (CO_2) from fires in the savannas are lower in quantity than the amounts bound into the biomass by photosynthesis and nitrification from the atmosphere during the year, or growing season immediately preceding the fire. Larger emissions can occur in the tree savannas when the woody plants have been burnt and have not regenerated.

Various stages of degradation and succession are recognizable in areas affected by fire depending on the frequency with which individual areas are burnt, whether the fire is at the beginning or later in the dry season and the length of the period since the last fire. The mosaic of vegetation in such areas, which is termed a *fire climax formation*, is a complex pattern parts of which may alter over time, but which, in the long term, is preserved basically. There will be changes in the structure only when fires no longer occur.

14.5.4 Biomass and primary production

The size of the *biomass* depends largely on the density and height of the tree cover. Since in most savannas the natural cover has been altered by human intervention, estimates of the total biomass do not indicate much about the ecology.

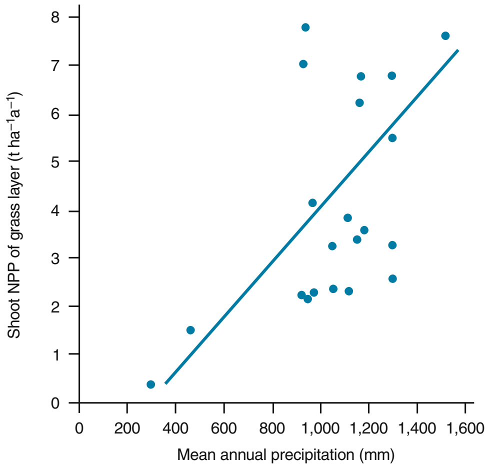


Fig. 14.10. Annual production of grass layer in the west African savanna in relation to the mean annual precipitation. The wide range of values reflect edaphic variations or variations in the density of woody growth at selected locations. Source: Ohiagu and Wood 1979

Biomass in the grassland savannas, as in the steppes, varies greatly with the season. During the dry season production can range from zero, immediately after a fire to the height of the net primary production towards the end of the rainy season. The actual amounts lie somewhere in between because not all the grass is burnt and part of the growth dies and drops off or is eaten by herbivores. The maximun herbaceous mass above ground is reached therefore before the end of growing season.

In addition to the seasonal variation, there are also considerable fluctuations from year to year because, particularly in the dry savanna, the production of grass in the years of high annual precipitation is much higher than in years with low rainfall totals. There is a fairly close linear relationship between the long term mean annual above ground primary production and the mean annual precipitation, similar to that in the Dry midlatitudes and the Dry tropics and subtropics. Figure 14.10 shows an example from west and central Africa. If South American savanna is included, a range of 5 to 7.5 kg of dry matter $ha^{-1}\,a^{-1}$ per millimeter of precipitation is estimated, a higher rain use efficiency therefore than the 4 estimated for semi-arid and arid regions (McNaughton et al. 1993; Chap. 13.5.4). If precipitation is higher, the linear relationship is not maintained because as the surplus of precipitation grows, more rainwater flows away unused, conditions that are similar to those in the moist savanna. The net primary production in the moist dystropic savanna is, therefore, at a similar level to the eutrophic savanna because the advantage of greater moisture is offset by lower soil fertility in moist areas. Where fertility is greater in the moist savanna, however, the net primary production and rain use efficiency increase with increasing precipitation (Werner 1991).

14.5.5 Zoomass and animal feed

Compared to other ecosystems in which herbivores eat less than 5 to 10% of the net primary production, in most savannas more than half the above ground herbaceous production and a quarter of the subsurface production is eaten by animals. Invertebrates consume more than the vertebrates. Grasshoppers and locusts are the primary consumers almost everywhere, together with caterpillars during the rainy season and roaches and crickets, which also eat dead matter.The most important secondary consumers include spiders and ants, many of which are omnivores. Among the detritus feeders, termites, ringworms, millipedes and the larvae of beetles predominate.

In some parts of the moist savanna in East Africa large mammals reach very high volumes of *zoomass* of from 0.1 to 0.3 $t\,ha^{-1}$, mostly elephants and hippopotamuses. Still 0.06 – 0.1 $t\,ha^{-1}$ zoomass is found in some dry savannas of East Africa. In addition to grasses, browsing of trees and shrubs are the main source of feed for large mammals. Food shortages in the dry season may cause stress for herbivores when the herbaceous plants and leaves die off, or if fire destroys the plants. The availability of food remaining in the dry season and after fire plays a major role in determining which species are present in a region and their densities. Many animals migrate to offset the lack of food in the dry season by concentrating near water sources or in valley bottoms supplied by groundwater or by moving to areas where rainfall is more plentiful.

The biomass consumed by animals (C) is only partly assimilated (A) into their bodies. The rest is defecated, often in a relatively unaltered form and is available to detritus feeders (Chap. 5, box 4). The *assimilitation coefficient* (A/C) of herbivores varies greatly among species. It is also affected by the age of the animal and the type of food. The A/C of mammals lies between 30 to more than 60%, much lower than most carnivores but much higher than the detritus feeders (Table 14.2).

Of all the energy assimilated by mammal herbivores, from 1 to 5% is used for production (P), that is growth or reproduction. Cold blooded animals have a much higher net production efficiency (P/A) with generally more than 10% and occasionally over 50% of the assimilated energy being used for production.

The gross production efficiency or ecological efficiency (P/C) can be estimated from the assimilation and net production efficiency. Table 14.2 shows that the gross production efficiencies range from 0.5% for elephants to 50% for spiders, that is 0.5% of the intake of feed is used for production, including reproduction, compared to about half for spiders. Values lie between 1 and 10% for most animals with warm blooded animals having the lowest values. Compared to impalas and cattle, elephants require four times greater quantities of feed to produce the same growth.

Grazing of the grass cover by wild animals and cattle, the removal of the living biomass, does not affect primary production of the grass layer, rather it increases production capacity, particularly of the grass shoots, provided feeding is distributed over the growing season and plants are not weakened.

Table 14.2. Turnover efficiency and rates of turnover of selected animals in the savanna (%)

	Assimilation efficiency A/C	Net production efficiency P/A	Gross production efficiency P/C	Rate of turnover
Herbivores				
Locusts				
– Burkea savanna (various species)	32	19	6	
– Acacia savanna (various species)	32	21	7	
– Orthochtha brachycnemis	20	42	9	9.6
Caterpillar				
– Cirina forda	43	15	6	
Herbivrous and Saprovorous termites				
– Trinervitermes geminatus			9	10.4
– Ancistotermes cavithorax (fungi cultivating)			2	9.7
– Hodothermes mossambicus	61			
Ungulates				
– Waterbuck (Kobus kob)	84	1	1	0.27
– Impala (Aepyceros melampus)	59	4	2	
– Domestic cattle (Bos taurus) Transvaal.	57	5	2	
– African elephant (Loxodonta africana)	30	2	0.5	
Carnivores				
Spiders				
– Orinocosa celerierae	95	53	50	
Detrivores				
Earthworms				
– Millsonia anomala	9	4	0.6	2

A = assimilation, C = consumption, P = production

Source: from Lamotte and Bouliere 1983

Generally an intake as feed from the grass layer of from 30 to 45% of the net primary production can be tolerated.

The above ground NPP is raised because the plant matter consumed is altered to a more easily decomposable form which accelerates the return of minerals to the soil. In this way, plant growth is benefited rather than reduced. Also, shadow from lower leaf stories is decreased by browsing. If light is a growth

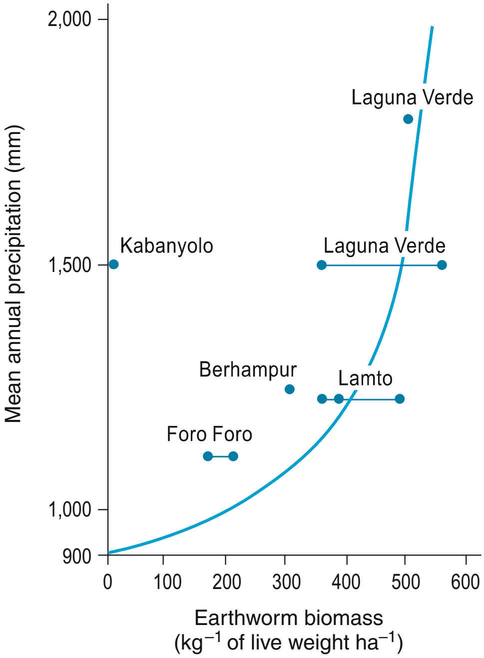


Fig. 14.11. Relationship between the size of the earthworm population and annual precipitation. Earthworms are active only when conditions are moist and are, therefore, most active in areas of high precipitation with long rainy seasons. During the dry season, earthworms move to the deeper soil layers. Source Lal 1987

factor, growth conditions are improved in this way too during the grazing season. Both compensate for the reduction of photosynthetically active parts caused by animal take off.

14.5.6 Decomposition of litter

Decomposition of organic matter is rapid if not by *fire* then, in the first instance, especially by *termites*. The highest densities of termites occur in Africa and Australia. Densities increase in relation to the amount of dead organic matter available from waste. The greatest production of waste is in the moist savanna where there are over 100 million termites per hectare with a live weight of 0.1 t ha^{-1}, compared to only a few million in the dry savanna. The proportion of waste consumed in relation to the total supply of waste remains more or less the same everywhere, unless fire intervenes to take over most of the decomposition process. From one fifth to one half of all waste is consumed by termites in these areas. Earthworms, leaf cutting ants in South America, millipedes and beetle larvae, the latter especially in Central America are the next largest consumers (Fig. 14.11). Fungi, actinomycetes and bacteria take care

Table 14.3. Nitrogen balance in two moist savannas

	Lamto (Ivory Coast) ($kg\,ha^{-1}\,a^{-1}$)	Venezuela (Trachypogon savanna) ($kg\,ha^{-1}\,a^{-1}$)
Input by rainwater	19 (4.5 anorganic)	2.6
Biological N_2 fixation		
– Blue green algae	–	0.7
– Microorganisms in root area	9–12	6.7
Loss by fire	17–23	8.5
Leaching	5.6	0.5
Balance	+3.9	+1.0
Source: Medina 1987		

of the final decomposition stage, returning the organically bound minerals to a single anorganic form which is then reavailable to the plants. This process of recycling, in effect the duration of the decomposition, usually takes place within a year, despite slowing during the dry season.

Humus formation in the savanna is relatively unimportant and the humus content in the soils, therefore, relatively small, as are supplies of nitrogen and phosphorus, which can be a limiting factor in production.

14.5.7 Mineral supplies and turnovers

The supply of *plant nutrients* in the soil is generally unfavorable, particularly in the moist savanna. It is important that the existing nutrient supply is maintained and losses are replaced. Grasses for example have a high ratio of roots to shoots, dense root systems connected with mycorrhiza and nitrogen fixing Azospirillum. Rhizobium, another nitrogen fixing bacteria occurs in root modules of most leguminous trees and herbs.

Nitrogen fixing and the input of nitrogen by rainwater equal, in the long term, the losses resulting from leaching in the soil and from the burning of organic matter during fires (Fig. 14.3). Phosphate losses are generally replaced from the atmosphere.

Forests have a lower mineral requirement per unit of growth (i.e. higher nutrient efficiency) than grasslands. On the other hand, the circulation of minerals in the trees is much slower and therefore much larger quantities of minerals are bound in their biomass. Thus, their apparent advantage resulting from their higher NUE can be ignored. The requirements regarding soil fertility for grasslands in similar locations may be higher, but the proportion of the total mineral supplies which is available for uptake is larger in grasslands.

14.6 Land use

The Tropics with summer rain are the most densely settled and agriculturally most intensively used areas of the tropics, with the exception of some former rainforest areas of Southeast Asia. Compared to the Tropics with year-round rains, the ecozone has several advantages. Soil fertility is higher and there is a winter dry period which allows clearing by fire in areas still covered by woodlands. Extensive grasslands are available for cattle grazing also, the high intensity of solar radiation at the end of the rainy season is advantageous for the cultivation of maize, sugar cane and cotton.

In most summers in the Tropics with summer rain the total precipitation and the duration of the rainy season are sufficient for the cultivation of a wide variety of crops: maize, sorghum, millet, cotton, peanuts, rice, various varieties of beans and sweet potatoes. Because of a dry period of at least three months, only annual plants are grown unless they can be irrigated, as in the case of sugar cane, or are relatively more drought resistant such as cassava or sisal. Coffee and tea are planted in upland areas where orographic rainfall and low cloud provide moisture during the dry season.

The cultivation of a range of crops combined with some animal husbandry is typical for the predominantly small farms in the ecozone. The integration of crop growing and the keeping of animals has traditionally not been strong but has increased as more animals have been used to pull plows and their dung used to improve soil. Feed crops are absent although the cattle, sheep and goats feed in the fields after harvest and on the fallow areas, or on any available natural pastures held in common.

Semi-permanent cultuvation with land rotation is still the traditional form of agriculture in many areas. Fields are used for several years and are then left as *fallow* for the soil to regenerate. Some use is made of fallow in grazing areas.

A measure of the relationship between the number of years a piece of land stays in cultivation and the number of subsequent fallow years can be expressed as a cultivation factor. For example if a five year cultivation period is followed by five years of fallow, the cultivation factor is 2. In this case a farmer requires two areas of similar size and quality to maintain the level of output on his farm.

A rotation factor is another measure in which the cultivation years are expressed as a reciprocal of the total area used for cultivation, usually $\times 100$. Five years of cultivation and five years of fallow would result in a R factor of $5/10 = 0.5 \times 100 = 50\%$, indicating an area for crop use of 50% and a fallow area of 50%. A land rotation system has usually a factor of $0.3 \leq R \leq 0.7$. In this case a subsistence farm would need $1\,^1/_2$ to 3 times more land than a similar farm with permanent arable cultivation. Where soil conditions are poor and a long fallow is needed to regenerate the mineral nutrient budget, even more land is required. This is true for many areas in the moist savanna and the tropical rainforests (Chap. 15.6). Figure 14.12 shows soil productivity in relation to the length of the fallow period in shifting cultivation over a period of 40 years.

Production on the traditional mixed farms is mainly subsistence. Hoe and plow drawn by oxen are still widespread. Apart form some irrigated areas productivity is also low.

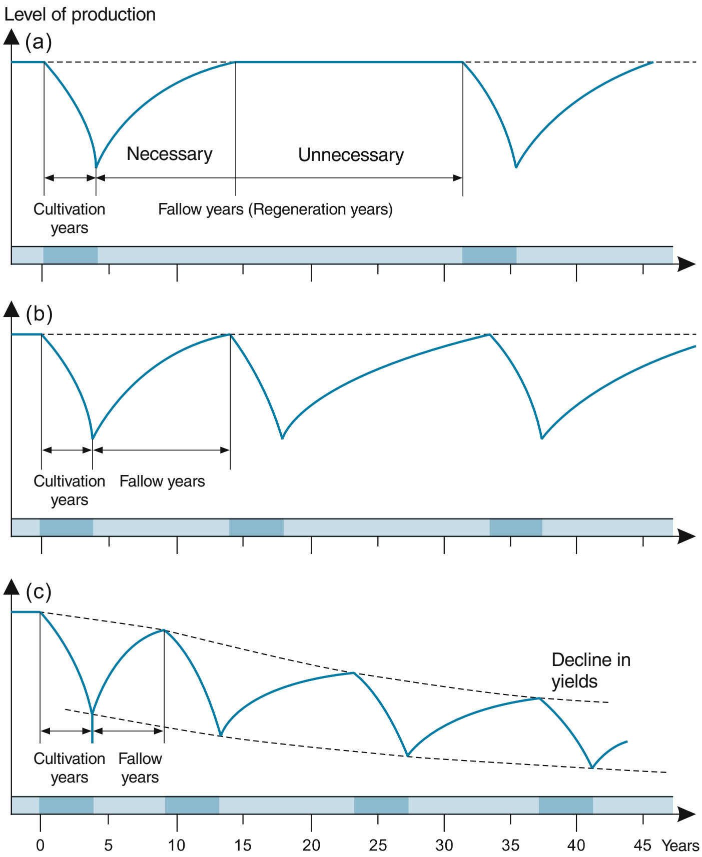


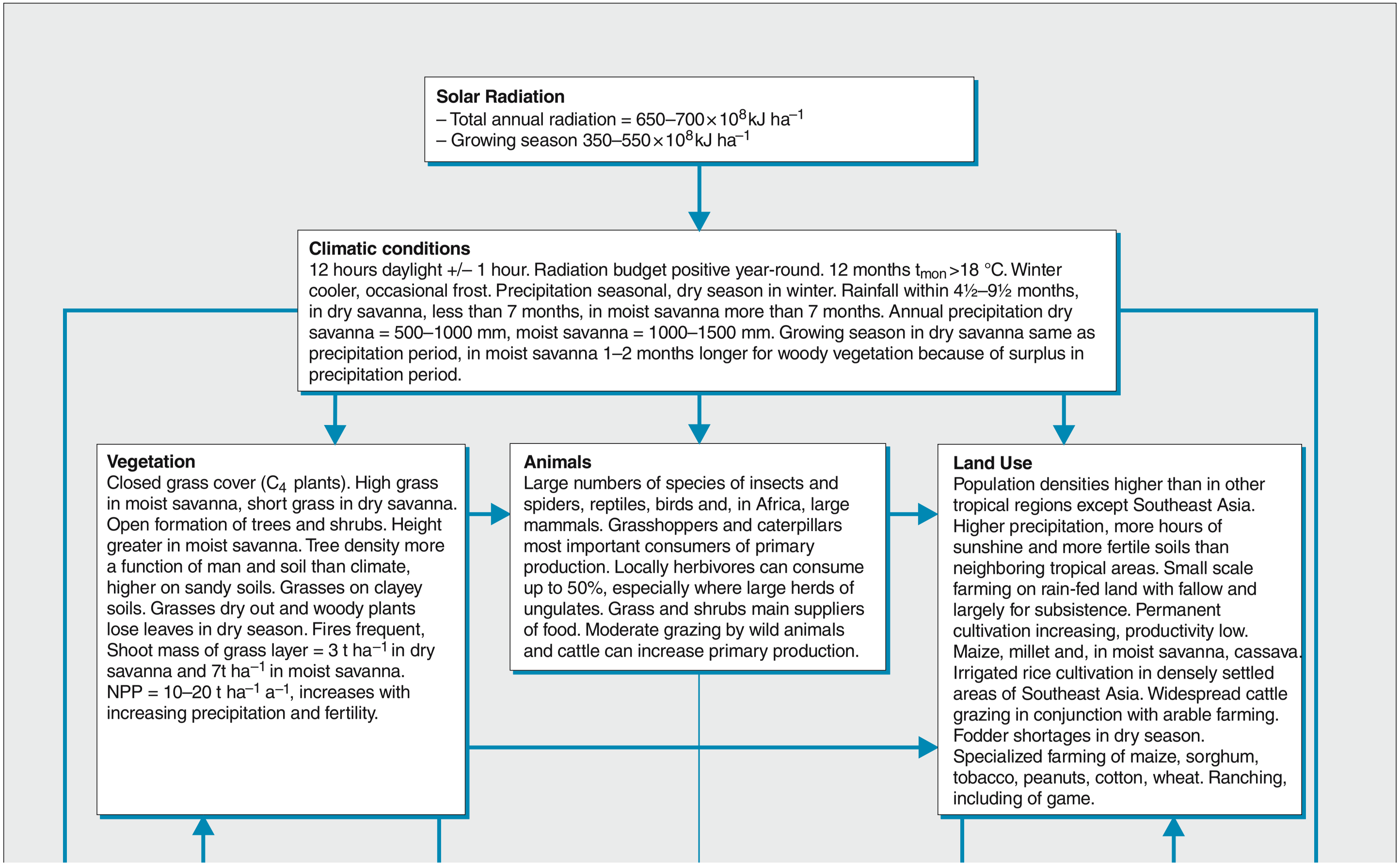
Fig. 14.12. Relationship between length of fallow and soil productivity in areas of shifting cultivation. In (b) the fallow period is equal to the period required to regenerate the productivity. In (a) the fallow is longer than necessary, in (c) the fallow period is not long enough to restore productivity and the yields per hectare decline. The figure also shows which rotation and fallow sequence brings the highest production over a longer period. With a shortening of the fallow period there are more harvests, which in time might compensate for the drop in yields per harvest, and this could in the long run – as long as the reduction of fallow periods is moderate – result in an increase of total production. Source: Ruthenberg 1980

Population growth and the consequent shortage of land has led to the replacement of the extensive shifting cultivation by a more permanent field system. An increased use of fertilizer has made this possible. Improved agricultural use of land within the forests has also reduced soil erosion and raised the quality of the organic content of the soil.

A major exception to the traditional extensive land use is the irrigated rice cultivation of Southeast Asia which covers large areas in both the Tropics with summer rain and the Tropics with year-round rain (Fig. 6.2).

Within areas of traditional cultivation, including irrigated areas, there are also commercial farms that specialize in the production of one or a few crops on relatively large arable farms. Maize, sorghum, tobacco, peanuts, cotton, wheat, coffee, tea and sisal are among the most frequent crops grown for commercial production. Cattle fattening and dairy farms have also developed. Commercial farms are often located along highways or form islands within an area of subsistence agriculture

In some areas of the savanna, in northern Australia, South America (Columbia, Venezuela, Paraguay and Brazil), Mexico and Kenya and Angola commercial cattle grazing has become established on large areas of unsettled land. Commercial grazing of wild animals has been attempted in several areas, including kangaroo in Australia, eland antelopes in Africa and capybaras in South America.


Solar Radiation
– Total annual radiation = 650–700 × 10^8 kJ ha^{-1}
– Growing season 350–550 × 10^8 kJ ha^{-1}
Climatic conditions
12 hours daylight +/– 1 hour. Radiation budget positive year-round. 12 months t_{mon} >18 °C. Winter cooler, occasional frost. Precipitation seasonal, dry season in winter. Rainfall within 4½–9½ months, in dry savanna, less than 7 months, in moist savanna more than 7 months. Annual precipitation dry savanna = 500–1000 mm, moist savanna = 1000–1500 mm. Growing season in dry savanna same as precipitation period, in moist savanna 1–2 months longer for woody vegetation because of surplus in precipitation period.
Vegetation
Closed grass cover (C_4 plants). High grass in moist savanna, short grass in dry savanna. Open formation of trees and shrubs. Height greater in moist savanna. Tree density more a function of man and soil than climate, higher on sandy soils. Grasses on clayey soils. Grasses dry out and woody plants lose leaves in dry season. Fires frequent, Shoot mass of grass layer = 3 t ha^{-1} in dry savanna and 7t ha^{-1} in moist savanna. NPP = 10–20 t ha^{-1} a^{-1}, increases with increasing precipitation and fertility.
Animals
Large numbers of species of insects and spiders, reptiles, birds and, in Africa, large mammals. Grasshoppers and caterpillars most important consumers of primary production. Locally herbivores can consume up to 50%, especially where large herds of ungulates. Grass and shrubs main suppliers of food. Moderate grazing by wild animals and cattle can increase primary production.
Land Use
Population densities higher than in other tropical regions except Southeast Asia. Higher precipitation, more hours of sunshine and more fertile soils than neighboring tropical areas. Small scale farming on rain-fed land with fallow and largely for subsistence. Permanent cultivation increasing, productivity low. Maize, millet and, in moist savanna, cassava. Irrigated rice cultivation in densely settled areas of Southeast Asia. Widespread cattle grazing in conjunction with arable farming. Fodder shortages in dry season. Specialized farming of maize, sorghum, tobacco, peanuts, cotton, wheat. Ranching, including of game.

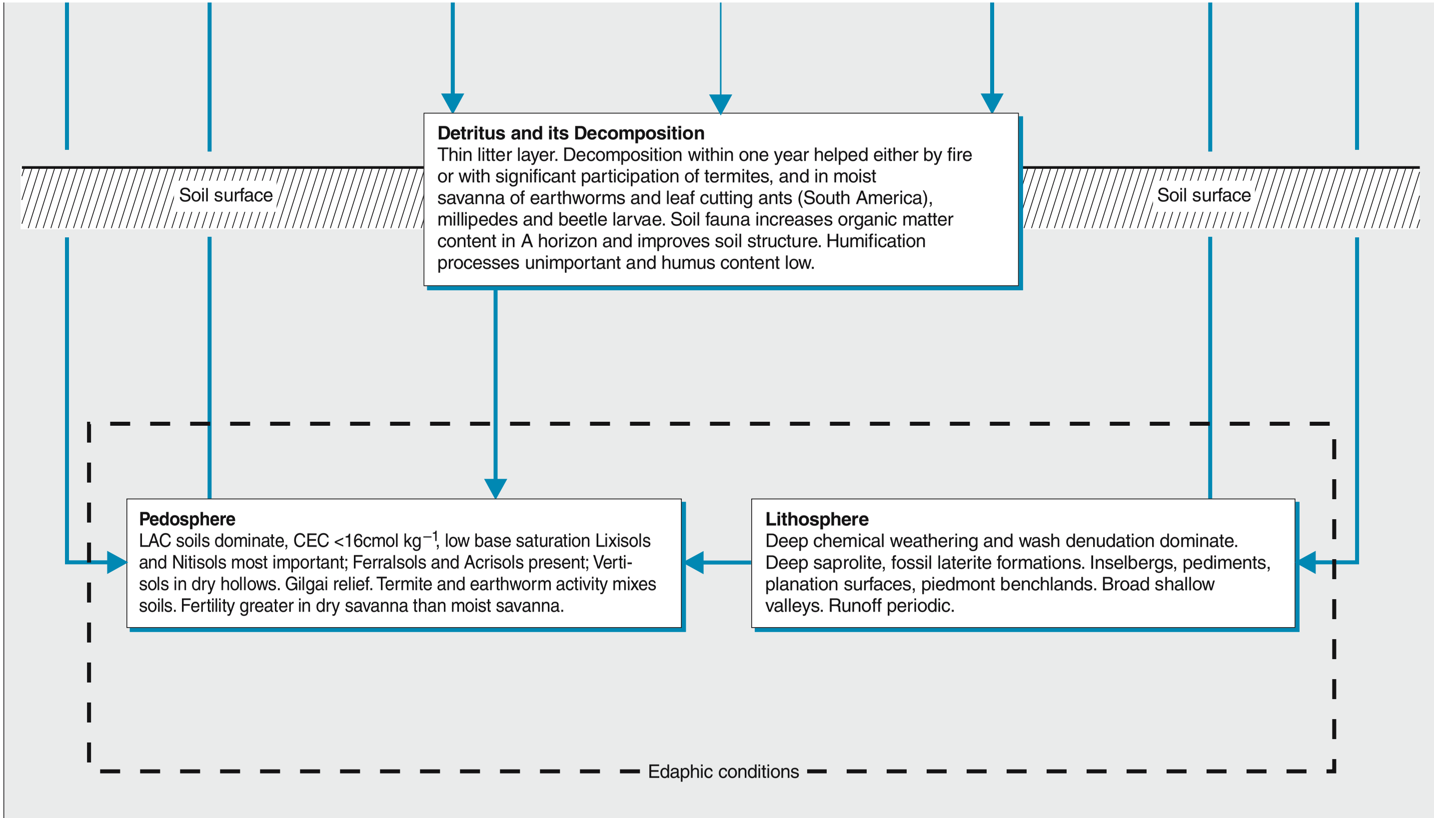


Fig. 14.13. Synoptic diagram for the Tropics with summer rain