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INTERNATIONAL POSTGRADUATE COURSE IN ECOLOGICAL APPROACHES TO RESOURCES DEVELOPMENT, LAND MANAGEMENT AND IMPACT ASSESSMENT IN DEVELOPING COUNTRIES (EMA)

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Centre for Protection and Improvement of Environment (Berlin) of the Ministry of Environmental Protection and Water Management of the German Democratic Republic in cooperation with the Technical University Dresden

Subject III: Agro-ecosystems: Land-use planning with special reference to infrastructure and regional planning

STUDY MATERIAL

elaborated by a team of authors under G. Franke and A. Pfeiffer

Volume One

1. General characterisation of arid and humid systems; irrigated and rainfed technologies

Volume Two

2. Ecology and cultivation of important crops
   2.1. Special problems of fertility and degradation of tropical soils

Volume Three

   2.2. Cultivation of important crops

Volume Four

3. Cultivation technologies, including site demands, energy demand, irrigation, crop protection, fertilization, harvesting, processing, marketing

Volume Five

4. Crop rotation, plantations

5. Ecological and economy-based cultivation strategies

6. Environmental impacts of major agricultural systems and practices, and possible countermeasures

Volume One

III. 1. General characterisation of arid and humid systems; irrigated and rainfed technologies
by W. Hain

Subject III: Agro-ecosystems: Land-use planning with special reference to infrastructure and regional planning

III.1. General characterisation of arid and humid systems: irrigated and rainfed technologies

III.1.1. The geographical delimitation of the tropics

III.1.1.1. Climatic factors as a basis for a differentiated subdivision of the tropics

Starting from the general definition of the climate given by PHILIPPSON (1933), who by climate understands the essential atmospheric phenomena at a place on the erath's surface, this term covers different spatial orders of magnitude.

a) The macroclimate, the overall climate of a region usually a large geographic area, is determined by the processes taking place in the higher atmosphere and, above all, by the differences in the configuration of the earth's surface over a large area. It comprises large areas such as countries and continents with climatic peculiarities and is used for the division of the surface of the earth into climatic zones.

b) The mesoclimate, terrain or local climate, is governed by the local peculiarities of the earth's surface, especially of the relief with different altitudes and slopes and the direction of the slopes. These factors exert an influence on irradiation and thus on temperatures, atmospheric humidity and air current as well as distribution of precipitation so that remarkable climatic differences may develop even within narrow limits. These factors exercise an influence especially on the growth of the plants. The macreclimate superimposes the mesoclimate.

c) The microclimate, the local climate of a given site or habitat, includes the climatic peculiarities of the air stratum immediately above ground on a small area such as a forest, a herbaceous soil-covering or a field. The different climatic elements are determined continuously and usually not summarised in the form of mean values. Here, everything depends on the determination of the variations and extremes of the climatic elements which are decisive for the growth of the plants.

Climate is defined as the mean condition and the ordinary course of the weather in a given place or site. While the climate usually remains constant, the weather changes continuously.

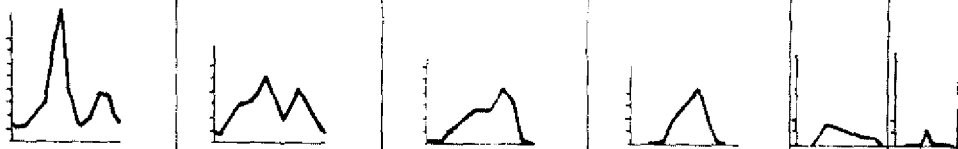
The problem of the representation of the climate is associated with the compilation of the weather that is continuously changing and the individual meteorological elements into an overall picture. KÖPPEN (1931) defines the main constituents of the climate as radiation, heat, atmospheric pressure, wind and water content of the atmosphere and the climatic elements as the mean air temperature, its annual and daily periodic as well as its mean non-periodic variations, and the absolute maximum and minimum of the air temperature.

Climatic factors are, above all, the geographic latitude, the elevation and the nature of the support on which the atmosphere rests, i.e. whether it is solid or liquid, its inclination towards the horizon and the kind of vegetation or the cover of snow and ice on this support, the dependence of the wind on the pressure distribution, the radiation and air temperature. This results in a complicated concatenation of cause and effect which cannot be surveyed easily and which normally cannot be subjected to exact calculations. KÖPPEN (1931) also points out to the variability or inconstancy of the individual factors of the weather in the various regions of the earth. He thinks the causes of the latter to be the occurrence and migrations of high and low atmospheric pressures under the most different conditions of radiation and the changes in the wind directions and wind velocities. While in the tropics the temperatures are relatively constant, extraordinarily great differences occur in precipitations in the individual months and years due to the above-mentioned factors. Therefore, the living conditions for the natural vegetation and the cultivated plants may be quite different within narrow limits while their causes are to be found both in the climate as a whole and in the mineral nutrient supply of the soils. From this, BLÜTHGEN (1966) draws the conclusion that any climate of any place on the earth as well as that of any part of a country as a whole represents an individual which is not repeated. There are, however, comparable similarities inherent in it, both with respect to effects and development, which give occasion to an abstracting typification. In any case, a classification and arrangement which are easy to survey are required although we know that an arrangement or subdivision into climatic zones which will meet all points of view cannot be presented. The criteria used are discussed in literature especially with respect to the division of climatic zones and the associated problems of the course of the limits of these zones.

Due to the fact that the interrelation between climate and vegetation and its association with the site are known, frequently the vegetation is used as an indicator for site properties (TÜXEN, 1935; ELLENBERG, 1956; and others).

For a subdivision of the plant cover into natural zones of vegetation, the heat and water conditions are of paramount importance which, in outline, are determined by the macroclimate and, in detail, by the mesoclimate and microclimate. Frequently, problems of the spatial subdivision of the vegetation are studied in order to obtain the delimitations of climatic altitudes (TROLL, 1956). Altitudes in mountainous regions frequently can only be characterised climatically by the change in the vegetation belts which mirror finer differences in the climate of the terrain. That is why the most differentiated representation of the various tropical areas was developed by botanists; an example is that of Africa prepared by KNAPP (1973). It is not possible, however, to provide coincidence between a representation of the climatic vegetation belts of the tropics with a precipitation map - not even if the number of months with precipitations is used in the place of the annual amount of precipitation. Therefore, the arrangement prepared

by JAEGER (1945) seems to be suitable for dealing with questions of the agricultural land-use in the tropics because it largely complies with the requirements of clearness. It is based on the duration of the rains and droughts. In representing his growth climate zones, JAEGER starts from the fact that the range of the tropics extends from the rain forest to the desert, from the continually moist tropics to the constantly arid areas, while the natural vegetation is modified accordingly depending on duration and abundance of the rains. The climatic transitions, however, are not provided in definitely delimitated steps but gradually in a way which MANSHARD (1968) tried to represent graphically in a simplified form (Fig. III.1 - 1). -
These growth climate zones of the tropics have been generally accepted and form the point of departure for further discussions of questions of agricultural land-use.

Number of humid (resp arid) months	10-12 (0-2)	9-10 (2-3)	7-9 (3-5)	3½ - 6 (6-8½)	2-3½ (8-9½10)	1(-11)	0(12)
Average annual rainfall in mm	mostly above 2 000 mm	mostly above 1500 mm	mostly above 1000 mm	750-1000 mm	>400 mm	below 400mm	
Schematic annual distribution of rainfall Examples							
Typical useful plants	India rubber, tropical woods	Palmtree, Cocoa, Coffee	Yam	Cotton, Millet, Peanut	Peanut		
Simplified sectional drawing							
Plantgeographical terms (MANSHARD 1960)	Moist indecidous woodland (Rainforest)	Monsoonforest	Moist savanna (Riverforest)	Dry savanna	Thorn savanna	Semi-desert	Desert

g. III.1.1. Schematical survey of the climatic vegetation zones (between equator and tropic) shown at the example of West Africa (draft W. MANSHARD 1973)

Growth climate zones of the tropics

Number of arid months (according to Lauer)	Division of the tropical lowland climate zones according to the duration of the drought (acc. to Jaeger)	Distribution of the most important widely distributed formation groups over the climatic belts of the tropical lowlands	
0			
1	Tropical rain forest climate zone	tropical rain forests	
			inundation savannas
2		seasonal and rain forests	moist savannas (with evergreen
3	Moist savanna climate zone	monsoon forests	galery forests)
4			
5		Campos cerrados and leaf-shedding dry forests	dry savannas
6	Dry savanna climate zone		(without evergreen galery forests)
7		thorn-tree succulent forests with	leaf-shedding dry forest or thorn-trees
8	Thorn savanna climate zone	thorn-bush succulent formations, thorn savannas	
9			
10		semi-deserts	
11	Semi-desert climate zone		
12	Desert climate zone	deserts	

On the variability of the precipitation distribution and its effects on the agricultural production

Of the natural site factors for the agricultural production, the soil with its properties, the thermal and growth-climatic conditions and the hygric annual balance is of paramount importance. In this connection, ACHENBACH (1981) points out: "While, in a long genetic process, the soil has become a substrate with almost invariable physical, chemical and biotic properties, the agricultural utilisation of a site must take into account the permanent variability of the climatic elements."

As to the variability of the precipitation, KÖPPEN (1931) mentioned already "that, in contrast to the uncommon constancy of the temperature, the rainfall shows very great and disastrous differences between the various years in many regions of the tropics and subtropics." - It is not the amount of moisture to be expected as the annual mean but the reliability and seasonal distribution, the variability of the moisture available annually and monthly that becomes the decisive factor of land-use." KÖPPEN (1931) ascertained that, for the entire earth, the ratio of maximum to minimum of the annual amounts of precipitation shows the following values as the result of studies conducted over a period of 30 to 50 years:

Amounts of annual precipitation	Minimum to maximum
200 to 400 mm	4.4 times
400 to 600 mm	3.3 times
600 to 800 mm	2.9 times
1,000 to 1,300 mm	2.4 times
over 1,600 mm	2.1 times

Other values are given by BRUNNER (1981) for the tropics and subtropics:

Amounts of annual precipitation	Variability of precipitation
150 to 250 mm	40 %
250 to 500 mm	15 to 40 %
600 to 1,200 mm	15 to 25 %
1,000 to 1,500 mm	10 to 20 %
more than 1,500 mm	below 10 %

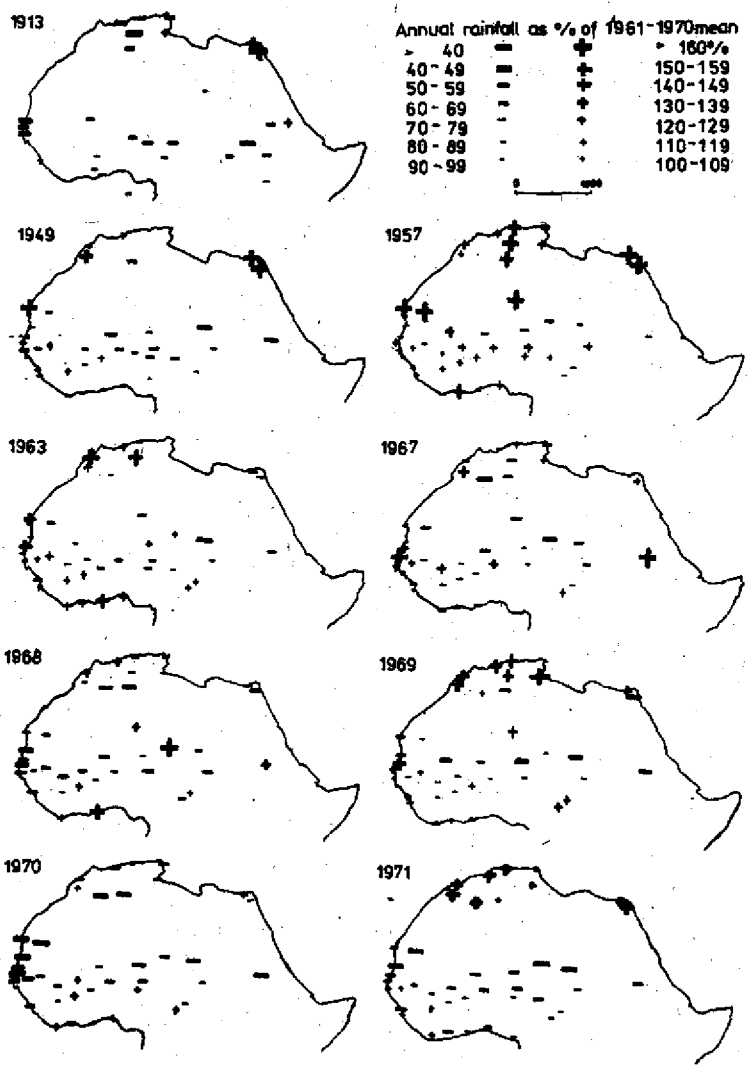


Fig.III.1.2. Annual rainfall as % of 1951 till 1970 mean

The above maps have been compiled by A.T.GROVE (to accompany the paper 'Desertification in Africa' pp. 33-45 above. Acknowlegments for assistance in their preparation are due to Miss P.A. MORGAN and Mr. A. CHADWICK.

A.T. GROVE, Cambridge, 1973

These two tabulated statements and the representation for the Sahel zone of Africa shown in the illustration on the previous page (Fig. III.1. - 2) mirror the same conclusions, namely, the lower the average amounts of precipitation over a period of many years, the greater the variability or the deviations from the long-term average values. This fact exercises not insignificant influences on the entire agricultural production. The variability increases the risk of cultivation and influences the crop yields. Seasonal droughts reduce the possibilities of cultivation while the yields are reduced by increasing droughts.

In the long run, such a risk limiting cultivation causes a negative site development which leads to the so-called "agronomic dry boundary". Studies conducted by ACHENBACH (1981) showed that, in accordance with the specific temporal and quantitative requirements for moisture of the individual cultivated plants, any useful plant should have its individual dry boundary, specified on the basis of these considerations. The term "dry boundary" as a collective name for the limit of cultivating non-irrigated field crops should be checked for this reason. In spite of this restriction of the predicative value of long-term mean-value statements , details of the distribution of precipitations including daily precipitations are unfortunately not always available. The example of the weather-station of Agrigento in Sicily will illustrate this problem:

average value of the station over a period of many years		508 mm
maximum rainfall	in 1957	899 mm
minimum rainfall	in 1922	187 mm

Years with amounts of precipitation which correspond to the calculated mean shown in the following illustration (Fig. III.1. - 3) are seldom. Years with the lower precipitations prevail.

A shortage of water of a long duration is frequently followed by an enormous excessive supply of water as is indicated in the illustration by Agrigento (Fig. III.1. -4). This weather-stattion measured a rainfall of 336 mm within 13 hours.

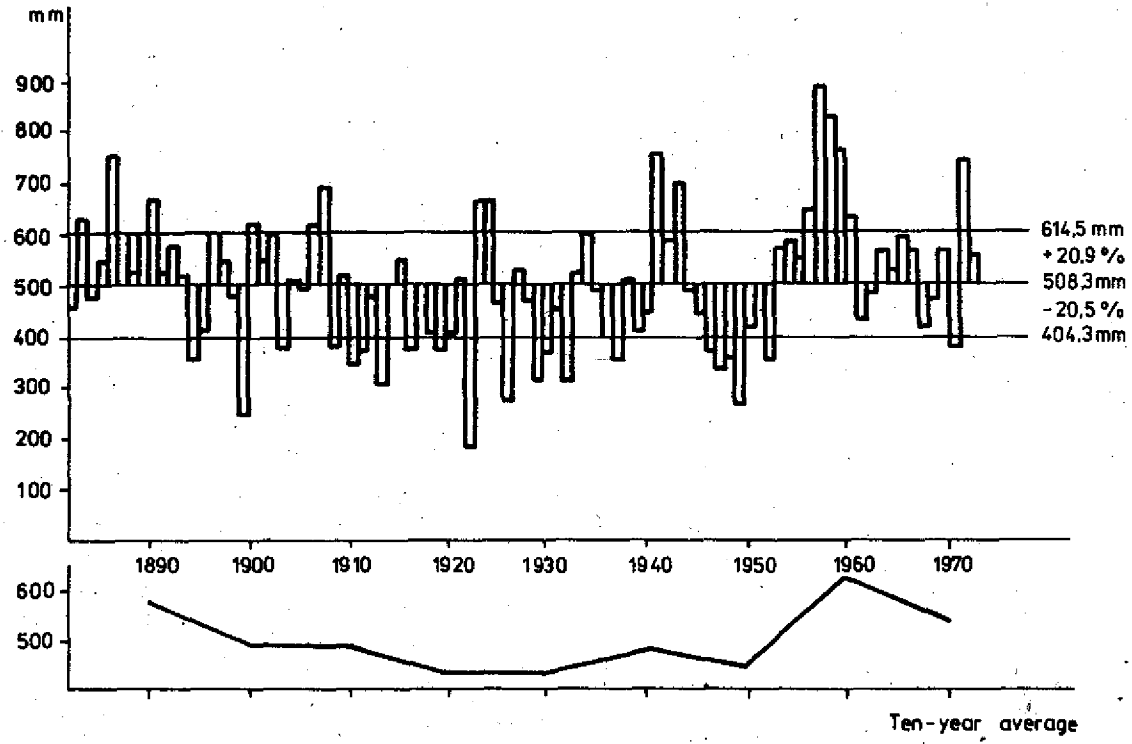


Fig. III.1.3. Variability of annual rainfall AGRIGENTO (1882 - 1972)
Calculated by the data from CRINO 1921
Ann. Idrol. 1921 - 72
Source: BAKE, G (1981)

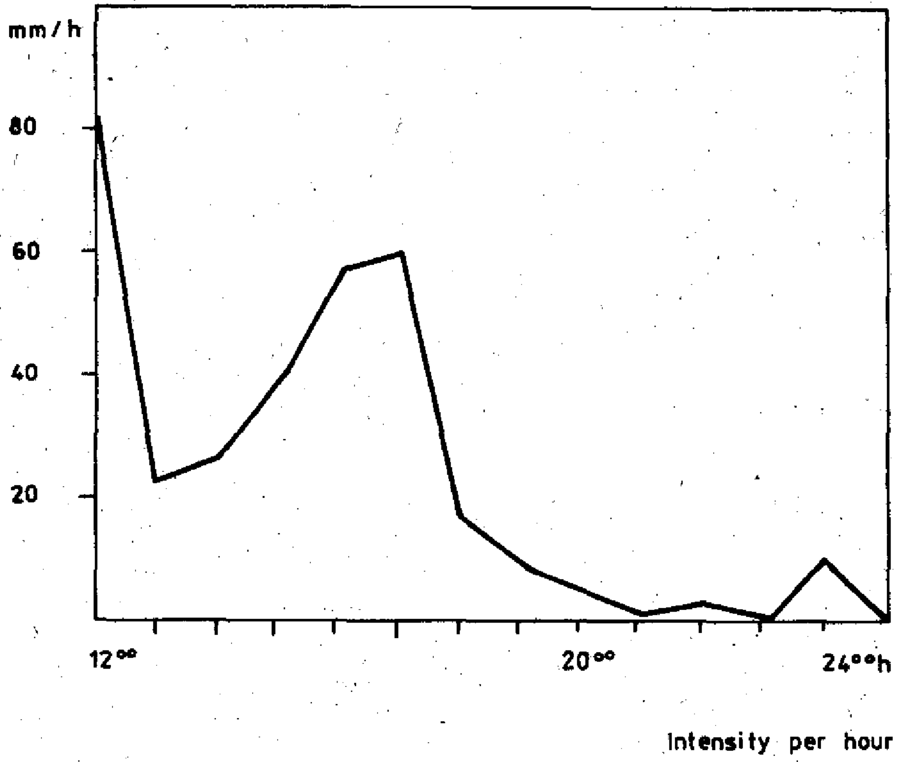


Fig. III.1.4. Intensities in AGRIGENTO on 27 and 28 September 1971
Source: own calculations by Ann. Idrol. 1972
Source: BAKE, G. (1981)

Similar data are available from other regions; for example, in 1966, in Cuba a rainfall of 900 mm occurred within 3 days with an annual precipitation of 1,300 mm or, on February 16, 1983, in a season when no rain falls in Cuba as a rule, 113 mm of rain fell within a few hours (tornado - cyclone). When long-term mean values are taken as a basis of precipitation distribution for characterising typical tropical and subtropical zones, then the fact should not be left out of account that considerable deviations from the mean values are not out of the question. These facts must be taken into consideration by the agricultural production. In this connection, we refer to the Table on page 14 a.

III.1.2. The natural conditions of production in the growth climate zones of the tropics

III.1.2.1. The evergreen tropical rain forest

Principally, the tropical rain forest is restricted to the equatorial range from 10° of northern to 10° of southern latitude. As to its extent, it is subjected to irregularities which are caused by the influences of the monsoon winds. Under these conditions, a displacement of the rain forest belt has been brought about. Thus, in parts of India and South China, the tropical rain forest can still be found at 23° of northern latitude up to the tropic - on the other hand, dry monsoons cause an omission of the zone of the rain forest close by the equator.

As to the distribution of the tropical rain forest, a distinction is made between three main areas:

a) The entire forest region of the Amazon which extends up to the east slopes of the Andes. Territorially, it is the largest area of distribution of the rain forest and situated mainly in South America.

b) The forest region of the Indo-Malayan area and the bordering parts of South-east Asia, the Pacific isles and North Australia.

Natural resources of agricultural production in the tropics

Types	Rainfall	Vegetation
1. Tropical rain forest	more than 1,600 mm 12 to 9.5 months humid 0 to 2.5 months arid	forest
2. Moist savanna	1,100 to 1,600 mm 7 to 9.5 months humid 1.5 to 5 months arid	forest woodland savanna
3. Dry savanna	1,100 mm to 500 mm 4.5 to 7 months humid 5 to 7.5 months arid	bush savanna grass savanna
4. Thorn savanna	500 to 250 mm 2 to 4.5 months humid 7.5 to 10 months arid	thorn bush grass savanna succulents
5. Semi-desert	250 to 50 mm 1 to 2 months humid 10 to 11 months arid	thorn bush grass savanna succulents
6. Desert	0 to 50 mm 0 to 1 month humid 11 to 12 months arid	no vegetation

c) The forest region of West Africa extending from Sierra Leone to Nigeria with branches to Central Africa up to Lake Victoria. Here, the rain forest partly extends only between 1° and 8° of northern latitude.

Apart from these main areas, the evergreen tropical rain forest is only found in the form of scattered areas on slopes of mountain ranges, e.g. in East Brazil and in East Africa on the slopes of the great volcanoes.

There are no well-defined boundaries between the tropical rain forest and other tropical forest formations because the neighbouring areas show transitional forms.

High and almost constant precipitations and high temperatures throughout the year are characteristic of the region of the tropical rain forest. The annual amounts of rainfall are more than 1,600 mm while amounts of 10,000 mm may fall on the Hawaiian Islands and up to 17,000 mm in the mountainous country of Bangladesh, the region with the heaviest precipitation in the world. The existence of the evergreen tropical rain forest depends to a smaller degree on the quantity of rainfall and to a much higher degree on the distribution over the whole year. In general, the rain forest is restricted to regions with maximum two dry months while months with less than 100 mm of rainfall are considered as dry.

The rains usually fall in the afternoon in the form of short thunder-showers which may also be prolonged into the night. Then it will clear up again. In the morning, it is foggy and dull and sweltering. The relative atmospheric humidity is rarely less than 90 % at 6 a.m. throughout the year. During the morning until noon the sun shines and then rain will fall again or a thunder-storm occur. This course of the weather will remain almost the same throughout the year apart from differences in the quantity of rainfall.

The monthly mean of the air temperatures is about 25 to 28 °C while the maximum scarcely exceeds 30 °C. The nightly minimum temperatures will scarcely drop below + 20 °C due to the intense counter-radiation of the moist air. The daily mean of the air temperature usually is anything between + 24 and 30 °C - while the average variations per day are only 6 to 8 °C and they are higher than the annual variations which are below 5 °C.

As compared to the open field of this zone, the climate in the rain forest is more balanced with small annual and daily variations of temperature. This is due to a inhibited air motion. This phenomenon usually is termed as "forest climate"; the atmospheric humidity in the forest is 6 to 12 per cent higher than that in the open field.

Heat and atmospheric humidity favour a deeply penetrating chemical weathering. Clay hydrates more or less coloured red by iron are concentrated in the upper layer of the soil. In general, there are no stones in the rain forest. Rocks may only be found on the banks of rivers subjected to heavy erosion, on steep slopes hollowed from below or in steep slopes of broken rock.

Outward appearance

As the name indicates, the evergreen tropical rain forest is evergreen. Although a certain rhythm in the shedding of leaves is given, the individual species of trees shed their leaves at different times. There are species which never shed their leaves while other species shed them every three to six years or at irregular intervals. The evergreen tropical rain forest is characterised by multi-layered "vegetation stories" which may comprise three to seven vegetation layers one upon another.

a) The uppermost or highest layer is represented by lofty trees, the"virgin forest giants", which reach a height of up to 40 and even 60 metres.

b) The tree layer proper with heights of 20 to 30 metres.

c) A shrub lyer which mainly consists of young trees.

d) The herbaceous layer - which frequently is not developed in the rain forest because the amount of light required for its growth is missing so that the number of species is largely reduced. Instead a large number of species of twining plants, parasitic plants such as lianas, lichens and mosses are existing on the trees.

e) The grass layer - which is nearly completely absent due to the lack of light so that usually the bare soil is present which may be covered by organic material subjected to decomposition.

Studies have shown that, due to the small amount of light incident upon the ground because of the multi-layered stories, a narrow selection of species takes place in the vegetation layers close by the ground because only 1 to 0.1 per cent of the light incident upon the forest penetrates through to the ground surface (SCHMITTHÜSEN, 1961).

Another peculiarity of the rain forest are the buttress roots which are quite frequently found. They offer the necessary lateral support to the lofty trees for their high growth. Due to the high groundwater table, these species of trees normally do not possess a deep-reaching system of roots, a fact which frequently leads to root competition. Another peculiarity of the tropical rain forest is the cauliflory of certain trees, e.g. cocoa. Luxuriant growth of the vegetation including a large number of species of trees forming the tree layers is typical of the tropical rain forest. KNAPP (1973) estimates that about 2,000 to 3,000 species of plants are to be found in the tropical lowland rain forest of Africa. The number of species is different in the various elevation levels and decreases with increasing height. WALTER (1970) reports that about 40 to more than 100 species of trees are found on a hectare which mostly belong to different families. The age of the trees can only be determined with great difficulties because annual rings are missing. Assessments on the basis of growth measurements showed that there are trees having an age of 200 to 250 years.

The continuous canopy formed by the natural vegetation breaks the impact of the heavy rainfall. The forest inhibits denudation but not the washing effect of the rain-water seeping through or of the soil water in the form of ground water flowing through. The

The mud of the rivers and the deposits in inundated flat land show that, under the tropical rain forest in connection with flowing and creeping motions of the soil, a considerably erosion, a removal of soil, takes place under the surface of the ground. There is an excessive supply of water in this zone, a narrow network of waters and rivers abundant in water.

A special form of the tropical rain forest are the mangrove forests. These are formed by maritime trees or shrubs, of the evergreen type, growing on salty and brackish-water coastal swamp at the mouths of rivers on the sea shore. These forest form an almost impenetrable thickets in which trees can reach heights of anything between 5 and 20 metres. When inundated by tidal flow, only the tree-tops project from the water - in the case of low tide, the lower parts of the trunks with prop roots or respiratory roots project from the mud. A continuous belt of mangroves will only develop in places where the surf is relatively weak. This is the case on the South Chinese coast up to Canton, on the shores of Florida and Cuba, on the south coast of Iran, and in the deltas of Mekong and Ganga. A distinction is made between various groups of species of mangroves.

III.1.2.2.

The moist savanna belt

Savannas belong to the scenery of the alternately moist tropics with rains and droughts of different durations, uniformly high temperatures but no frosts. Between the various savanna types there are numerous transitions whose boundaries can rarely be indicated exactly in the landscape.

On either side of the equator, the belt of the moist savannas is adjacent to the tropical rain forest while the transitions between rain forest and moist savanna are fluid. According to KÖPPEN (1923), this zone is included in the tropical rain climates of the inner tropics and characterised as "subhumid". The regular change from the rains to droughts is characteristic of this type of landscape. The authors give different data on the duration of the rains and droughts. In the discussion below, we refer to the generally accepted representation according to LAUER (1952) and JAEGER (1956). These two authors give for moist or humid savannas a rainfall distribution which covers 8 to 10 humid months and 2 to 4 arid months per year. The amounts of rainfall are between 1,600 mm and 1,100 mm.

The outward appearance of the humid savannas is characterised by the presence of hydrophilic woods, still present forms of the rain forest and monsoon forest, evergreen coastal and galery forests and transitions to grassland. If, during a period of 2 to 4 months, there is a certain shortage of rainfall, a lack of water for the growth of the plants will not occur because sufficient moisture is contained in the soil ensuring favourable conditions of growth of evergreen forests and herbaceous and grass formations. A storage of water by the plants (succulence) does not take place because the plant roots usually reach the ground water even during the drought.

In the humid savanna, we find continuous forests having a height of growth of 20 to 30 m including the monsoon forests of South-east Asia, there are the lower savanna forests having a height of growth of 6 to 12 m, grass savannas including individual trees, and evergreen grass savannas. Where growth of trees occurs in the humid savanna, it is not uniform. A great number of variations is possible ranging from evergreen, high forests including many species through to the species of trees shedding their leaves during the drought. When the tree layer or individual species of trees shed their leaves during the drought, then evergreen plants are still present in the understory and in the herbaceous layer.

Moist forest strips are distinguished from the following landscape formations by the fact that they cannot be cleared by burning on a large scale in order to turn them into usable land. During the drought, people try to clear areas of the transitional region by burning. After the destruction of the plant cover, secondary formations such as bamboo and several metres high hard bunch grasses develop. The numbers of species of the leafy mixed wood decreases with increasing distance from the equator. Not infrequently, damage due to erosion occur in heavy rainfall, especially on slopes. At present, the moist savanna belt is primarily used for crop farming. The typical form of land-use is rain-fed cultivation.

III.1.2.3. <u>The dry savanna</u>

The zone of the dry savanna is a small belt, i.e. a belt of limited width, situated between the moist savanna and the thorn savanna. The dry savannas rank amongst the regions of the alternately humid-arid tropics and are called "semi-arid". Between moist savanna and dry savanna, the Penck's dry boundary is situated which is based on calculations which results in a balance between annual amount of precipitation and monthly evaporation (precipitation = evaporation). JAEGER (1945) found for Africa this boundary to be 8 humid months with about 1,100 mm of rainfall and for South America to be 7 to $6^1/2$ humid months.

Large areas of the dry savanna are found in the Zambesi basin, in the southern part of the Sahel zone, in East Africa, in West Madagascar, they form a belt ranging through India, and are situated in northern Australia, in parts of Mexico and Brazil.

According to LAUER (1952) and JAEGER (1945), areas with 4 to 8 humid months and 4 to 8 arid months per year are called dry savannas. The precipitations amount to 1,100 to 500 mm (according to ANDREAE (1977) to 600 to 300 mm!).

The character of the landscape is distinguished by trees growing at a more or less wide spacing so that, frequently, it is compared to orchards. A typical feature is the grass plain with 1 to 2 m high hard-leaved grasses which, however, do not form a continuous grass cover.

The tree formations mainly belong to the deciduous dry forests which reach a maximum height of 5 to 8 metres. They have short trunks of hard wood with wide tops which become green during the rains. Another typical representative of the dry savanna is the baobab which determines the character of the landscape.

According to VAGELER (1955), in the dry savanna, the ligneous plants frequently recede into the background. He thinks this is attributed to the impermeable clayey soil present over large areas which, during the drought, prevents water from getting into the deeper soil layers. During the rains, air is lacking for the deeper root layers and, as a consequence, tall grasses thrive all the better.

Particular types of the dry savanna landscape have special names: In the south of Africa there is the "grass-woodland", open woods where the trees have umbrella-like tops and grass is growing which are called "miombo". In Farther India, teak forests (Tectonia grandis) and sal forests (Shorea robusta) are found. The Indian plants including Dipterocarpus and the Mimosa trees including Fuberculatus are typical of the dry savanna in Burma; various acacia species including the gum arabic tree are found in Africa both in the dry savanna and in the thorn savanna.

While rainfall decreases in the area towards the thorn savanna, the trees increasingly develop thorns. The growing of thorns and the succulence (juiciness) are features of plants indicative of the fact that they adapt themselves to the dry weather. Here, leafless ligneous plants with succulent trunks and succulents having the shape of chandeliers and growing to a height of 10 m are the outstanding features of the landscape.

The plants are evergreen on river banks with galery forests, in gullies and basins of wells and in areas where the ground-water table is high.

III.1.2.4. Thorn savanna

On both sides of the equator, thorn savannas are adjacent to the dry savannas and are included in the dry climate of the external

The boundary between dry savannas and thorn savannas, the "agronomic dry boundary", is considered to be the boundary for a rain-fed cultivation. For Africa, FALKNER (1938) ascertained 8 or 4 humid months per year.

The region of the thorn savannas comprises areas with 8 to 10 arid months and an uncertain rainfall between 500 and 200 mm. In older publications, this region is also termed as "thorn shrub steppe" x) (WAIBEL, 1933) and "thorn bush".

The long season of drought causes the plants to adapt themselves to the given natural conditions. The latter are characterised by an extraordinarily intens solar radiation, high heat, great variations between day and night temperatures and shortage of water.

The range of the thorn savannas comprises large parts of South-east Africa and the Kalahari, the northern regions of the Sahel zone across Africa, the southern Somalia and South-east Ethiopia, parts of North-west India, the Deccan, North-east Brazil, a wide zone of North Australia and parts of Madagascar.

The landscape of the thorn savanna is coined by ligneous plants which occur in the form of shrubs attaining a height of 1 to 3 m and thorn trees with umbrella-shaped tops and growing isolated. TROLL (1951) compiled the following features of this natural vegetation formation:

- The growth of thorns is the dominant feature of the ligneous plants.
- The plants store water, leaf and trunk succulence are dominant.
- Plants of different forms store water in their roots.
- In contrast to trees growing in other regions, the majority of trees found in the thorn savanna have thin smooth barks which from time to time become detached from the trunk in the

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x) The term "steppe" in the more recent literature is only used for regions with a hot summer and cold snaps in winter - that is to say, only for regions beyond the tropics.

form of scales and paper-like stripe (due to this form of growth, an assimilation via the bark is possible).

- A refinement of the leaves of trees and shrubs in the form of subdivisions of the structure of the leaf is typical.
- Cacti and succulent euphorbias coin the landscape whereas lianas and twining plants rarely occur.

  The growth of grass is scattered and its height only 30 to 50 cm. The grass forms bunches of hard grass which sometimes are widely apart. - They become green during the rains and dry up in the long dry season.
- Along wadis, the bed of streams in arid regions that is usually dry except in the rainy season, woods of the type of the deciduous dry forest are present. Umbrella-shaped thorn trees occur in an isolated manner which bear leaves for a short time only.

The zone of the thorn savanna is primarily used for pasture farming. In places where river or well water is available, irrigated crops are grown.

III 1.2.5. <u>Semi-deserts</u>

The largest desert regions of the earth are in the trades climate of the horse-latitudes. They for a dry belt over which the dry trades blow. This region is amongst the dry climates of the external tropics and considered fully arid.

The largest areas of distribution are the desert zones of North Africa (Sahara) and Arabia, large desert areas are situated in North America and southern California, in Colorado,North Mexico and Arizona.On the southern hemisphere, the Atacama is found in North Chile which extends almost to the equator, in South-west Africa the Namib and in Australia the great Australian desert. The semi-deserts are located about these large desert areas of the earth and are distinguished from the full deserts mainly by the flora. The dominating forms of growth are dwarf shrubs, semi-shrubs, small hard bunch grasses and succulent plants (trunk and leaf succulents). The plant formations appear in the form of points and frequently grow at a distance of several metres from each other. The parts above ground are small and low - possess, however, a deep and far-reaching root system whose lateral extent also determines the interspace between the plants. KNAPP (1973) states the existence of 500 to 1,000 species in the semi-deserts of Africa.

There are 10 and 11 arid months in the semi-deserts, the possibility is given, however, that rainfall between 50 and 200 mm may occur, mainly in the summer months. These rains, which only fall exceptionally may, however, be so heavy that they turn the otherwise dry wadis into torrential streams for hours. Flat land is flooded while the water masses do not erode. The cause may be the water-repellent effect of the parched ground. The rainfall is sometimes so heavy that one violent shower supplies up to 25 per cent of the annual total precipitation.

It can be stated that, due to the extreme dryness practically through the entire year, an intensified selection of the natural vegetation takes place and, compared with the thorn savanna, a further stunting of the vegetation takes place while the number of species of plants is further reduced. Parts of semi-deserts are used by nomads breeding camels for pasturing.

III.1.2.6. Full deserts

The boundaries between the above semi-desert and the desert are again overlapping as it is the case with all geographic large formations. In general, the desert is considered as that range which is beyond the cultivated zone, i.e. it is not utilisable. According to other ideas, deserts should be called only such regions which remain without any precipitation for a prolonged period of time, normally several years. LAUER (1952) states that the annual precipitations for deserts are less than 50 mm. In wide areas of this region, rain may be wanting for a period of several years.

Different though the deserts may be, one feature they have in common, namely, the adaptation of the natural vegetation to the climatic conditions. KNAPP (1973) ascertained 300 to 500 species of plants still existing in the desert zone of Africa. Nevertheless, the outward appearance of the deserts is characterised less by the plant growth but more by the type of soil surface. Thus, a distinction is made between the various types of desert, namely, rocky desert (hammada), pebble-strewn desert (serir), gravel desert, loam desert, marl (dust) desert, sand desert, salt desert and clay desert. Different vegetation features are characteristic of the various regions. This vegetation has been adapted to climate and soil.

Due to the unrestricted irradiation and emission, the daily temperature variations are very high in the deserts. For example, in the Algerian Sahara, in Egypt, in the Kalahari and in other regions it reached 17 to 20 °C (Timbuktu) in certain months. Consequently, night-frost may occur even in the lower latitudes which may drop down to -10 °C in normal years. During the daytime, temperatures up to +40 °C and more can be measured in summer. The air is usually very dry and the relative atmospheric humidity is about 20 per cent. Due to the high temperatures and atmospheric dryness, not infrequently the dreaded sand-storms with wind velocities of 30 to 35 m per second occur in summer which sometimes cause considerable damage.

In semi-deserts and deserts, an exuberant and multifarious vegetation exists where there is a water supply furnished by local springs or wells or by local seepage or by water flowing from a distant source either naturally or through artificial irrigation. These areas (oases) are largely used for crop farming today.

III.1.3. The agricultural land-use in the tropics

The natural "growth climate zones" of the tropics with their specific conditions of climate, water supply, soil and relief offer quite different preconditions for the agricultural production. In the following representations, the author takes advantage of this arrangement (see Fig. III.1. - 5) in order to classify the land-use in the tropics in three main groups to obtain a clear survey.

- Agricultural land-use in the humid tropics
- Agricultural land-use in the alternating humid-arid tropics
- Agricultural land-use in the arid tropics

The forms of land-use in the various main zones are the subject of the further representations given below.

III.1.3.1. Agricultural land-use in the humid tropics

The full extent of the humid tropics is about 16 million km^2 or 10 % of the solid surface of the earth.

The traditional form of land-use is shifting cultivation by using hoes. With this way of cultivation, an area of maximum 1 to 2 ha per family are primarily used for the production of foods for self-sufficiency, and to a limited extent some products are cultivated as cash crops. The development of the population, especially in this region, calls for the transition to new and more intense forms of land-use. This means disengagement from the traditional shifting cultivation by using hoes with a view to producing more goods for marketing in addition to foods.

In the last few decades, the following main forms of land-use have been developed in accordance with the climatic conditions of the humid tropics:

1. Shifting cultivation by using hoes
2. Shifting cultivation by using ploughs for tilling
3. Permanent cultivation by using ploughs and fertilisers and with a shortening or omission of the fallowing period
4. Permanent cultivation of tree and shrub crops
5. Multi-stage cultivation of different crops and trees on the same area
6. Irrigated farming of special crops

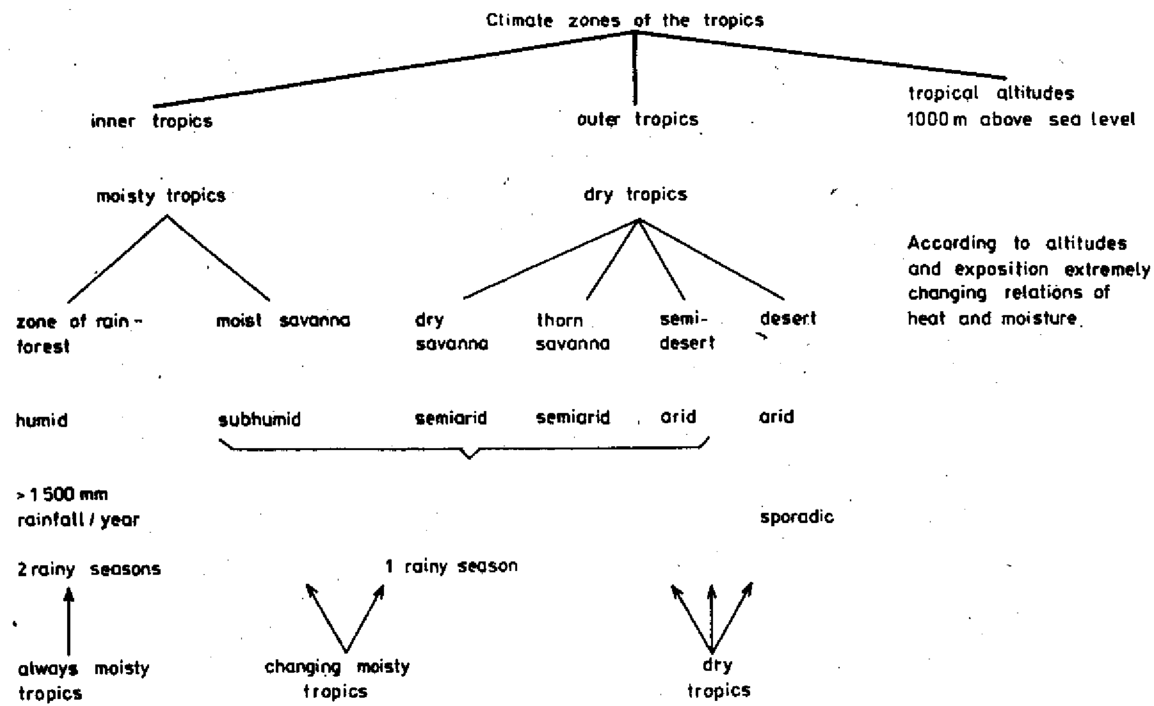

Fig. III.1.5. Climate zones of the tropics Source: ANDREAE, B. (1977)

This series of cultivation methods complies with the requirement of increasing the crop yield per unit of area and, at the same time, the labour productivity; it is not obligatory in any case, however, because individual forms may be developed depending on the local situation.

Shifting cultivation by using hoes in the humid tropics

Shifting cultivation by using hoes is one of the oldest forms of land-use. The typical feature of this way of land-use is the employment of the most simple agricultural implements such as hoe, digging stick and machete for harvesting. When using these simple implements, it is hardly possible for a family to farm an area which is larger than 1 to 2 hectares. This area is used for the cultivation of food crops for subsistence such as cassava, batatas, yams, maize, rice and vegetables such as tomatoes, red pepper, melons, aubergins, cucumbers and the like for a period of 3 to 4 years. Due to rainfall throughout the year, a distinct seeding and harvesting season is not given. Seeding and harvesting are possible throughout the whole year, and the crops are grown in a mixed manner on the very small plots.

With this form of land-use without an application of fertilisers, the yields decrease remarkably already after a short period, as is shown by the examples given by NYE and GREENLAND (1960):

maize	1st year of cultivation	100 %	- full crop yield
	2nd year of cultivation	80 %	- of the preceding year
	3rd year of cultivation	55 %	- of the 1st year of cultivation
maize	1st year of cultivation	100 %	- full crop yield
	2nd year of cultivation	48 %	- of the preceding year
cassava	1st year of cultivation	100 %	- full crop yield
	2nd year of cultivation	65 %	- of the preceding year
rice	1st year of cultivation	100 %	- full crop yield
	2nd year of cultivation	65 %	- of the preceding year
	3rd year of cultivation	47 %	- of the 1st year of cultivation
rice	1st year of cultivation	100 %	- full crop yield
	2nd year of cultivation	25 %	- of the preceding year

Due to the reduction of the yield, the subsistence farmers clear a new plot of land for reclamation; this calls for a great amount of manual work. For regeneration of the soil fertility, the plot no longer used is left as fallow land for 10 to 20 years, and a wild growth of bush, shrub and grass vegetation develops. This method of farming is called land rotation with bush fallowing in general while RUTHENBERG (1967) calls it "original crop rotation" and ANDREAE(1977) "field-wood crop rotation". The term of farming on the basis of clearing by burning seems to be inexact because due to considerable rainfall, clearing by burning is not always possible. The way of clearing or land reclamation is not characteristic of the overall cultivation.

Land-use by shifting cultivation by using hoes necessitates the change of the ground plots while the residence is not changed today, as a rule.

Due to the extraordinarily low labour productivity based on the use of simplest tools, it is rarely possible with this way of cultivation to produce cash crops. In some cases, especially where the territorial traffic conditions are favourable, bananas, citrus, coffee, palm oil, pineapples or other fruits are produced and offered in local markets. Since these products are cultivated by practically all families, sale is not guaranteed.

The result of such a type of farming is permanent lack of money. Money is missing for the purchase of consumer goods and all the more so for buying better means of production such as tools and implements, high-quality seeds, fertilisers and plant protection products. As a consequence, the living standard is extremely low, and there is scarcely any chance for an improvement of the material and social situation of the subsistence farmers under capitalist conditions.

This form of shifting cultivation by the use of hoes, and shifting cultivation in general, are only possible in thinly populated regions because the cultivated areas required are a multiple of those areas used in permanent cultivation.

Shifting cultivation by using ploughs in the humid tropics

A higher form of land-use is shifting cultivation by using ploughs, a method which is defined by the author as a larger area on which a main crop grows and which is farmed uniformly.

This method of shifting cultivation is based on the use of the plough or other tillage-equipment drawn by animal or motorised means of traction. When using this equipment, larger areas of land can be farmed and more products marketed than in shifting cultivation by using hoes. Shifting cultivation by using ploughs ensures a better field rotation which can inhibit an early impoverishment of the soil.

This method of an organised shifting cultivation calls for higher expenditures of capital for draught animals or tractors, but it enables several harvests on larger areas in a year under humid conditions. A problem remains the risk of erosion due to violent showers. Therefore, carefully selected areas which are not situated on slopes should only be used for this type of farming. Crops suitable for shifting cultivation of this type are tropical root and tuber crops, rice, maize, pineapple and sugar cane and the like. This form of land-use will only become efficient with the transition to the permanent cultivation of field crops because the clearing and developing operations repeated again and again and the costs associated with them will then be omitted.

Permanent cultivation of field crops

Due to the rapid growth of the population, also in the countries of the humid tropics, land is no longer available in an unlimited measure. The traditional methods of farming of shifting cultivation by using hoes or ploughs, which were largely adapted to the natural ecological conditions, are extensive with respect to the land requirements and involve high expenditures of labour. That is why many scientists and governments call for the surmounting of the old forms of land-use. Instead of the traditional way of land-use, modern methods based on the use of agricultural machinery, fertilisers, plant protection products and high-quality seeds should be used in order to ensure an increased commodity production.

Studies and investigations conducted in the last few decades have shown that the permanent cultivation of field crops is possible under humid tropical conditions. Although the majority of families employed in agriculture conduct land rotation farming because of the lack of material preconditions for other methods of farming, the examples show that permanent cultivation is economically justifiable provided certain amounts of capital are invested.

The courses prusued for the realisation of these aims are quite different. In recent years, state large-scale projects have been translated into reality in various countries of different social orientations. Governments have developed large lands, which were carefully selected in order to obtain relatively thinly populated areas so that continuous areas having a size of several hundred hectares can be provided. Sometimes, old settlements are included in these projects. The former land users receive land in other places, usually in marginal situations. The former subsistence farmers have the chance of being employed by the large-scale farms.

These large farms use modern technical means. For the levelling operations, bulldozers and other equipment are employed. Ploughing is performed with the help of tractors and trailed equipment, harvesting by means of combine-harvesters and other harvesting machines, depending on the crop in question. Modern methods of production are used in general.

Starting from the rise in prices for foods, that has taken place in recent years, a great number of private land owners have proceeded to intense cultivation. State machine stations were provided for the reclamation of large areas which, for the new agricultural entrepreneurs, clear the the land by means of bulldozers, level it and perform the first ploughing operations.

According to the principles of farm management, these areas are cultivated by wage workers and seasonal workers with the help of modern technical means. Only one crop is grown, e.g. rice or maize, and fertilisers are applied. The wages for the agricultural workers sometimes have the form of fertilisers which are used by the latter for their small holdings. Some of these new agricultural entrepreneurs are active in several villages and, thus, manage large agricultural areas where two crops can be harvested per year.

This group of persons receives credits from banks - while small holders have been considered not to be trustworthy now as before. Frequently, these agricultural entrepreneurs are corn merchants, administrative officials and other well funded persons who are interested in the utilisation of their capital. And quite a number of "village chiefs" have proceeded to the replacement of the traditional form of shifting cultivation by using hoes by a permanent cultivation of land (example of Nigeria).

In countries with socialist orientation, the transition from shifting cultivation by hoes and by ploughs to the permanent cultivation of field crops is effected by the creation of state pilot objects on reclaimed land or by uniting farmer into cooperatives which introduce modern methods of production into practice with state assistance and gradually within the scope of the economic possibilities.

<u>The permanent cultivation of tree and shrub crops</u>

The group of perennial useful plants, whose products are utilised by the producer or sold, comprises the tree and shrub crops such as the coco-nut palm and the oil palm, the species of citrus, cola- and mango trees, coffee, caoutchouc, cocoa trees and a great number of other fruits which sometimes are only of importance to the local region.

As to the land-use by these tropical crops, there are no differences with respect to cultivation both in large-scale farming and in small holdings. In any case, the soil is planted with tree and shrub crops for a period of several years.

The fact that large-scale farming, cultivation of land by small holdings and medium-sized farms as well as wild-growing or non-utilised tree and shrub crops co-exist is characteristic of the present cultivation of tree and shrub crops in the tropics. The stands and growths of this and that form serve for the maintenance of the ecologic equilibrimm, their stands and growths which are up to 100 years old inhibit erosion.

Quantity and quality of the products to be produced are determined by managemental points of view; in this connection it is of importance that, in recent years and in many places, a purposive instruction of small holders for the cultivation of high-quality products and their joint processing in the form of cooperative preparing and processing plants has been conducted by state or semi-state organisations in tropical countries.

In the last few decades, the frequently described "single-crop farming landscapes" have also changed. To an increasing extent and favoured by the state, a greater variety in tree and shrub crops has developed in the form of mixed crops. MANSHARD (1968) reported of a combined alternating row cultivation of coffee and papaya in East Africa, of oil palm and cocoa in West Africa - of coffee, mango, avocado and banana - of coffee and cola. In ethiopia, the cultivation of coffee and oat is combined, in South-east Asia, the cultivation of coco-nut palms with different fruit trees.

Such cultivations, provided they are expediently arranged, also enable the utilisation of slopes,which may be provided in terraces or not, that is to say, of areas which cannot be utilised for growing permanently certain field crops or which can only be used for this purpose under difficulties. As to the water requirements of individual tree and shrub crops, concrete data are available (FRANKE, 1982); these requirements can be met by additional irrigation if the rainfall is insufficient.

Multi-stage cultivation

Another form of the more intensive utilisation of land is the multi-stage cultivation. This name is used for the systematic common cultivation of several crops, namely, tree or shrub crops in combination with annual field crops or root and tuber crops on the same area. The individual crops are grown in rows, i.e. in stages somewhat resembling the natural structure of the tropical rain forest. It is the aim of this form of land-use to achieve a soil covering throughout the whole year in order to counteract the risk of erosion.

By planting rows of trees across the most frequently occurring wind directions, the violence of tropical storms and downpours is mitigated and, at the same time, the striking of the rain upon annual field crops is prevented to a certain extent.
In this form of land-use, quite different combinations become possible. Thus, oil palms and tropical timbers (including teak) are planted as the uppermost"stage", while coffee, cocoa, cola, citrus and other plants are grown as another "stage" - sometimes plantations of bananas or plantains are combined with maize, pulse crops or lucerne or with root crops in West Africa on larger continuous areas by scientific test stations and training farms and recommended for practical application by them. A systematic cultivation and tillage by means of tractors of the individual crops is possible provided the combination is favourably selected. Labour peaks can be reduced by this diversification and soil productivity and soil preservation are improved. This form of land-use, which can also be used by large farms, complies best with the natural conditions of the humid tropics and will certainly be propagated further.

Irrigated farming of special crops

Irrigated farming of special crops occupies a special position in the humid tropics. Although normally more than 1,600 mm of rain fell practically throughout the whole year, the areas involved are additionally irrigated during the almost dry spells in order to ensure two or three full crop yields, e.g. of rice. In this way, the risk of cultivation is reduced, taking the variability of the rainfall distribution into consideration. In years or months with sufficient precipitations, an additional irrigation is not necessary as a rule. Since sufficient water resources are available on the banks of rivers and lakes, retaining basins and the like, additional measures of irrigation can easily be taken in the case of need, depending on the water requirements of the individual crops. At present, however, these measures are restricted to special crops and specialised farms.

III.1.3.2. Agricultural land-use in the alternating humid-arid tropics

The alternating humid-arid tropics comprise the subhumid and semiarid regions on the surface of the earth with an extent of 19.6 million km^2 on 4 continents and 48 countries. The rainfall is 600 mm on an average per year for the dry savannas and 1,500 mm for the moist savannas. The natural conditions for the agricultural production are characterised by one or several rainy seasons. The length of the vegetation period is depending on the duration and intensity of the rains. The dominating form of land-use is rain-fed farming. The employment of human labour prevails in the field works. New forms of land-use have developed in this climate region of the tropics in recent years which are associated with an intensification of production. The forms of land-use in the alternating humid-arid tropics are as follows:

1. Seasonal shifting cultivation by using hoes
2. Seasonal shifting cultivation by using ploughs
3. Permanent cultivation based on rainy seasons and in combination with animal hsubandry
4. Irrigated farming of special crops
5. Irrigated farming in combination with animal husbandry

Seasonal shifting cultivation by using hoes

In contrast to the humid tropics where shifting cultivation by using hoes takes place on areas cultivated with crops enabling the harvesting of 2 to 3 crops because of the high annual precipitation, the seasonal shifting cultivation by using hoes in the alternating humid-arid tropics is dependent on the seasonally different amountsof rain and their distribution. The limits of a warranted cultivation vary from 400 to 500 mm of annual precipitation for cultivated plants having low water requirements such as the millets to anything between 800 and 1,200 mm of annual precipitation for maize, barley and tuber crops. Besides the various grain varieties, oil plants such as castor bean plant and sesame, the tropical root and tuber crops and various species of vegetables are grown on the basis of the seasonal shifting cultivation performed by the use of hoes.

Tilling is performed by means of simple tools such as hoe or digging stick. Immediately before the onset of the rains, holes are dug or pierced into the ground with different spacings - up to 1 m in squares - into which the seeds are put after the first wetting. Sometimes, manual broadcasting is performed. The area for sowing is dependent on the number of family members who take part in the hoeing and planting operations, and its size will hardly be more than 2 to 3 hectares. Apart from occasional weeding, no other cultivating operations will be performed. The use of fertilisers or plant protection products is not common in this simple way of land-use. When milk ripeness is reached by the cereal crops, frequently swarms of birds occur which cause considerable damage. The flight of birds is opposed by guards with noise-producing instruments or shot-guns driving away the birds. Depending on the species of useful plants, the harvest is started after 90 to 120 days. Since the kernels of tropical cereals are not shed, the harvesting period may be extended over a prolonged time. The crops are harvested by cutting off and gathering the ears, panicles and cobs. Threshing is performed by means of crooked sticks.

Similar to the situation in the humid tropics, the seasonal shifting cultivation by using hoes calls for a change of the land under cultivation after a few years because the soil will fail to produce the desired crop yield. Due to the fact that the rainfall is reduced as compared to the humid tropics, the natural growth of grass and bushes is not so exuberant as in the humid tropics. This facilitates the land rotation, on the one hand, but increases the danger of erosion due to violent showers and wind, on the other.

Seasonal shifting cultivation by using ploughs

Seasonal shifting cultivation of this type may be defined as the farming of larger continuous areas by means of draught animals or tractors and ploughs and other equipment. For the reclamation of land for this purpose, in the past frequently the method of clearing by burning was used because other technical means were not available. In recent years, this way of land reclamation has been abandoned more and more and will further recede into the background. Several governments have issued a ban on clearing by burning in order to protect the natural resources of their countries. FRANKE (9168) points out to the problems associated with clearing by burning and the effects of fire on the soil fertility and compares advantages and disadvantages of this method.

In recent years, new methods of land reclamation have been used which are based on the employment of bulldozers with pushing blade, chain clearing and other equipment. It must be taken into consideration that shifting cultivation by using ploughs with a cultivation period of 2 to 4 years is followed by a fallowing period of 1 to 6 years; during this latter time the natural growth consists almost completely of grasses, herbs and shrubs which can be ploughed up or mulched relatively easily.

In recent years, seasonal shifting cultivation by using ploughs has been subjected to changes in the methods of land reclamation but these have not been the sole changes. In the past, in the monsoon regions of South-east Asia, water-buffaloes were used as draught animals in agriculture and, in less wet regions, cattle - oxen and bulls - for tilling whereas, at present, tractors are also used for tillage in the alternating humid-arid tropics. In many cases, the reclamation of large tracts of land and their tillage has only become possible by the employment of tractors.

Since, during the drough because of the hardening of the soil, tillage is rendered difficult or even impossible, the tilling operations must be carried out at the most favourable time, that is, at the beginning the rains when the ground is wetted on the surface and down to a certain depth. For tillage in the alternating humid-arid tropics, implements should be employed which crumble the soil, do not turn it or turn it slightly only but mulch organic matter. Therefore, implements with disks or tines - those resembling the traditional hook plough with iron tip - are particularly suitable for tillage under these conditions. A preliminary cultivation of the soil after harvest is problematical because the mulched material is quickly decomposed under the prevailing climatic conditions so that it is no longer available for the new growth in the forthcoming season. The soil will harden again until the beginning of the new rainy season.

Just like the optimum time must be observed for tillage, for seeding only a certain period is available. When moisture further penetrates into the soil, tilling by means of animals or tractors is scarcely possible because they will sink into the wet soft soil. Water-buffaloes are an exception because they have prooved successful in the wet soil as draught animals.

The traditional methods of land-use with the help of draught animals is associated with additional problems because after the drought, the animals are in a bad nutritional condition and their performance is low. Therefore, tractors increasingly gain in importance for land reclamation and tillage of large tracts of land. Due to a mechanisation of the cultivation operations and an improved tillage, yields of maize were increased by 50 per cent and those of groundnuts three times, as tests have shown. When using modern technical equipment in the alternating humid-arid tropics, a second seed and harvest become possible under favourable conditions of rainfall, besides a reclamation of large tracts of land.

In order to attain a quantitative and qualitative increase in the quotas of land-use, the introduction of a system of crop rotation which is adapted to the natural conditions is necessary so that the years of fallowing can be reduced.

<u>Permanent cultivation of field crops in combination with animal husbandry</u>

The transition from seasonal shifting cultivation to permanent cultivation of field crops is not sharply defined and is increasingly characterised by the introduction of a crop rotation adapted to the climatic conditions. While in shifting cultivation a fallowing of several years is required for the regeneration of the natural soil fertility, recently, field grass has been cultivated for several years instead of fallowing on the basis of scientific findings; this grass is sued for animal husbandry as pasture or for the preparation of hay or silage. ANDREAE (1977) reports about crop rotations in Kenia where, after the cultivation of grass for three years, potatos and beans - wheat and barley followed. Instead of wheat and barley, pyrethrum and maize are grown. After three years of ley farming in Malawi, tobacco - cotton - groundnut -cotton - maize are grown and then again ley or field grass is grown for another three years. The proportion of ley in crop rotation is between 33 and 50 per cent. A similar rotation is widely used in Cuba where, after the cultivation of sugar cane for several years, ley is grown for pasturing for a prolonged period of time. When the soil is kept under a plant cover throughout the year, it is possible to counteract the loss of humus, to limit the damage due to erosion and to reduce the washing away of nutritive matter without the necessity of keeping a wood or grass fallow for many years. Another point of view should also be observed. With grwoing population, an increasing proportion of the available ground must be utilised. When the areas available for grass or wood fallow are reduced, then the regenerating function of the unused fallow can be replaced by ley cultivation in the alternating humid-arid tropics. In order to take advantage of the growing fodder, a close connection with animal husbandry must be established.

In more densely populated regions, where a fallow period is not favourable for economical reasons, the transition to permanent cultivation of field crops is effected by the application of mineral fertilisers. Tests conducted by IITA in Nigeria (Ibaden) for a period of many years including the permanent growth of maize on the same area for 10 years and two crops per year have shown that it is possible to maintain the yield potential of the soil on the same level by the application of fertilisers over a prolonged period of time. Therefore, the increased application of fertilisers is absolutely necessary for the permanent growth of field crops in the alternating humid-arid tropics.

Irrigated farming of special crops

Irrigated farming is more important in the alternating humid-arid tropics than in the humid tropics. When providing irrigation systems, it is possible to change the natural hydrologic conditions in such a way that large areas, which were not used for agricultural production because of the unfavourable conditions of rainfall, can be included in agricultural production.

By a water supply, additional to the rainfall, not only the water requirements of the cultivated plant in question is ensured but also a supply of organic and inorganic matter provided. The latter serve for the nutrition of the plants and the improvement of the soil. An increasing soil salinisation is problematical, however, and it must be solved in accordance with the local conditions.

Irrigated farming offers the advantage of achieving higher and constant crops in the region of the alternating humid-and tropics. The high investments for the erection of dams, pumping stations and for the construction of irrigation canals call for an effective organisation and management of the land-use.

Larger irrigated areas in Africa are, among others, the Gezira scheme with the Managil extension, the inner delta of the Niger in Mali, the Kilombero and Rufiji irrigation project in Tanzania and projects in Sambia, Kenia and other countries. - Most of these irrigation projects were initiated during the colonial period. Apart from regions where irrigation farming already has an old tradition (South-east Asia, North Africa and the Near East), the target was the production of products which were of interest to the colonial powers and found a ready market. Thus, the main products of these irrigation systems were cotton, groundnut, sugar cane, bananas and other export crops.

After the political independence of these tropical countries, the existing production structure has been retained while a greater diversification has been aimed at. A crop rotation has been introduced which is better adapted to the national needs of the country in question, that is, more attention is paid to the cultivation of food crops and fodder plants. Examples of this are the Gezira scheme and the Khasem El Girba project in the Republic of Sudan.

Irrigated farming in combination with animal husbandry

Besides irrigated farming which is mainly directed towards the production of export crops, in the last few decades irrigation works have been constructed in the alternating humid-arid tropics where particular emphasis were placed in the development of animal husbandry already at the stage of planning. By a reduction of the fallow periods and the introduction of a crop rotation adapted to the local conditions, it has been possible to increase the share of foder in the total production and thus to develop the fundamentals of an effective animal husbandry. This form of land-use enables the utilisation of the soil for the production of both plant and animal foodstuffs. Various farms, especially those in the neighbourhood of cities, specialise on the milk production and, in accordance with this special produce, grow the fodder required for this purpose on irrigated areas. The cultivation of such fodder plants as lucerne, green forage millet, maize and fodder grasses is widely spread. State, cooperative and private enterprises are well-known which have specialised on this branch of production. Examples are the Kuku cooperative plant and the private enterprise of Belgravia-Dairy in the Republic of Sudan.

III.1.3.3. Agricultural land-use in the arid regions

The arid regions in the tropics comprise the thorn savannas, semi-deserts and deserts with a rainfall of less than 500 mm. They cover a total area of about 25 million km^2 or 17 per cent of the solid surface of the earth.

The forms of land-use in the arid regions are restricted to pasture farming and irrigated farming in accordance with the climatic conditions because arable farming without irrigation is no longer possible.

The main forms of land-use in the arid tropics are:

1. Pasture farming by full nomadism
2. Pasture farming by semi-nomadism
3. Stationary pasture farming
4. Stationary pasture farming with partial storing of fodder
5. Irrigation farming without animal husbandry
6. Irrigation farming with animal husbandry

Pasture farming by full nomadism

The precipitation conditions and, thus, the growth of the natural vegetation must be considered the most important preconditions for the territorial distribution of pastoral nomadism. The isohyet of 100 mm is in general considered as the lowest limit of pasture farming - provided that, besides the moderate growth of grass, water places or river water is available for drinking - water supply for the population and for the livestock. Between the isohyet of 100 mm and that of 300 mm, the main area of the camel breeders is situated. Pasture land subjected to annual precipitations between anything of 200 and 400 mm are suitable for sheep husbandry. Areas exposed to rainfalls between 300 and 500 mm per year are used by camel, sheep and cattle breeders as pasture land. Regions having an annual rainfall of more than 400 mm and a relatively exuberant growth of grass during the rains are particularly suitable for cattle breeding. Per 100 mm of rainfall, a growth of 1 ton of fodder per hectare is expected in the form of dry substance (without underground roots).

The precipitations lessen with increasing distance from the equator whil the variations of rainfall become greater. Vegetation duration and vegetation density also become smaller. The main vegetation is formed by drought-resistant grasses and thorn bushes. The water supply beyond the rainy season must be ensured by making available the required amounts of water for the animals. Frequently, the pasturing radius is limited by the absence of drinking water for the herds. RUTHENBERG (1967) states that the maximum distance of the pasture from the watering place is 80 km for camels and 4 km for cattle.

Due to the still prevalent mode of thinking and living of the nomadic breeders who make great efforts to possess large herds, the livestocks have continuously increased during the last few decades so that the rate of stocking has become excessive. The possession of livestock still today is the most essential criterion of the social position and the personal reputation of a family. This applies to camel, cattle, sheep and goat breeders.

The commercialisation of the livestocks has been and still is the utilisation of the milk and the wool. A minor role is played by the utilisation of the meat, hides and skins. Nomadic breeders seldom sell or slaughter an animal. Normally, the breeders do not grow cereals; since their food, however, consists not only of milk products and game which is hunted but also of grain, every year a few animals only are bartered against cereals or sold. The distances from local markets sometimes are very large so that breeders visit them only occasionally, one time or two times a year. Nomadic breeders living in the vicinity of larger places or towns are an exception. The still existing mode of thinking and living of the breeders inhibits the development of modern animal husbandry and its inclusion in and utilisation within the scope of the national economy and the planned development of the latter in these countries.

Pasture farming by semi-nomadism

A special form of pasture farming is the semi-nomadism. Semi-nomads are occasionally settled breeders. A distinction can be made between two forms:

a) During a part of the year, the family and its herds are at one and the same pasture. When the fodder has been grazed down, the whole family starts migrating to look for new pasture grounds.

b) A part of the family, namely, older members of the family, sick persons and women with infants have their residence. The other part of the family, usually young people and men go with the herds to pasture grounds which sometimes are far away.

As permanent or temporary residences, banks of rivers and water place are preferred. In these two forms of nomadism, the people grow millet or vegetables with the help of irrigation in the vicinity of their domiciles to a moderate extent.

Nomadic pasture farming calls for a regulation of the right of grazing including the observance of seasons for the regeneration of the pastures. The consequence of an excessive rate of stocking were disasters which recently have occurred in various parts of Africa. This should be prevented by educational work and state measures.

Experiences gathered during the settling of nomadic breeders and the increase in the living standard associated with it as well as improvements of the social and other living conditions have shown that it easier to tie a part of the family to a certain domicile than to turn the whole family with their herds into resident breeders or farmers.

Stationary pasture farming

Stationary pasture farming calls for higher amounts of rainfall and a better growth of fodder associated with the latter. The lowermost limit for a stationary pasture farming is considered to be more than 200 mm for sheep and more than 300 mm for cattle per annum. In regions where more than 350 mm rain falls per year and the pasture is accordingly better, a specialisation in various branches of production is possible (ANDREAE, 1977). In contrast to nomadic pasture farming, the pasture grounds of stationary pasture farming are limited by wire-fences or electric fences, and additionally the enclosed area is subdivided. This enables a better control of grazing, favours the selection for breeding and a grouping of the animals according to age groups and branches of production such as breeding, fattening and milk production. In this way, care of the pasture and in association with this a better protection of the ground can be ensured. The erection of fences is not necessary in any case, however, if, depending on the size of the available pasture ground, supervision of the herds by herdsmen is ensured.

Stationary pasture farming with additional storing of fodder

Due to the high variability of the annual precipitations and their seasonal distribution, efficient pasture farming calls for the storage of additional fodder. The methods of making available additional fodder during the period when the growth of forage is restricted may be quite different. The simplest way is the purchase of feeding stuffs such as sorghum, straw, lucerne hay and other feeds from regions where crop farming is prevalent.

The quite different by-products obtained in the processing of cotton, groundnuts, sesam and other crops in the form of pellets or residues from sugar cane processing also serve as additional feeds. In regions where possibilities of forage production during or after the reany season exist fodder can be kept in store in the form of reserve pastures. The keeping of fodder in store is favourable in any case in order to avoid a drop in output during the time when fodder is scarce and to mitigate drought disasters with high losses of animals.

Irrigation farming without animal husbandry

Just like in the alternating humid-arid tropics, land is used by irrigation farming and the cultivation of special crops in the arid tropics. Since, as a rule, no or very small amounts of rain are available for cultivation, irrigation of the areas under crop must be effected during the entire year. If river water is not available, the fixed capital expenditure and the operating costs will be considerably increased by the operation of water pumps throughout the year. A profitable production will here only be possible by the cultivation of special crops such as vegetables in the vicinity of towns or other crops of particular importance to the national economy. The production costs in agriculture are particularly high, for example, in Kuweit and Saudi Arabia where process water for agricultural production is prepared from salt water, a procedure which entails enormous costs. Another example is Lybia where in desert regions water is obtained from deep-drilled wells for agricultural production.

For the last-named forms of land-use, national-economic points of view are decisive for production while considerations of farm management recede into the background.

Irrigation farming with animal husbandry

The majority of families engaged in agriculture in the arid regions cultivate irrigated areas in order to provide themselves with the necessary plant and animal products. The supply of useful water is usually effected from rivers and retaining basins. Along the banks of rivers or canals, the main proportion of the population is living. For example, about 70 per cent of the total population of the Republic of Sudan live at the Nile and its tributaries. In Egypt, about 80 per cent of the population find their livelihood at the Nile, In other regions, beyond the river zones, water is made available by the construction of shaft wells or deep-drilled wells unless springs are existing (oases). The latter form of land-use is only of local importance and is found on restricted sites only.

For the realisation of new irrigation projects with animal husbandry in arid regions, territorial national-economic points of view are also decisive. Under extreme conditions, various products cannot endure transports taking a prolonged period of time without decrease in quality. This especially applies to the supply of fresh milk to large towns. Therefore, in recent years, larger state, cooperative and private farms were established in the close vicinity of towns which are active in this branch of production. Above all, territorial points of view determine this production which is associated with relatively high costs of production.

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