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<u>Subject III:</u> 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

<u>Volume One</u>

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

<u>Volume Two</u>

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

<u>Volume Three</u>

2.2. Cultivation of important crops

<u>Volume Four</u>

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

<u>Volume Five</u>

III. 4. Crop rotation, plantations

III. 5. Ecological and economy-based cultivation strategies

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

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

III.2. Ecology and cultivation of important crops

III.2.1. Special problems of fertility and degradation of tropical soils

III.2.1.1. Introduction

The utilisation of the primary production of matter by the plant as a source of industrial raw materials and as foods and feeding stuffs is one of the most decisive forms of intervention by man in the natural ecosystems. The degree of man's intervention is extraordinarily variable but may lead to the complete deformation or destruction of natural ecosystems, on the one hand, and to the development of new and highly productive ecosystems which are in equilibrium and whose existence and stability is only ensured by virtue of the continuous intervention by man, on the other. This especially applies to agro-ecosystems. Unfortunately, the agricultural production contributes in various forms to the destruction of its basis of existence, namely, the soil and soil fertility. Various historical circumstances, which sometimes were inevitable, have to be considered the causes of this. When analysing the different manifestations of soil destruction and decrease in soil fertility, then it becomes obvious that two basic errors in the conceptional approach to land use form the root of the disastrous extent of soil degradation, namely:

1. the lacking consciousness of the limitation of regional and global soil resources in general, and in particular to agricultural use,
2. faulty criteria for the judgement on agricultural production technologies and the results of this production.

In view of the latter aspect, the insufficient attention paid to the unalterable interrelation between plant cover and soil within the ecosystem, especially between plant cover, biological activity in the soil and terility, plays a particular part. The phenomena of soil degradation can only be overcome when the efforts for an increase in production within the scope of agriculture and forestry start from the principle that modern production technologies have to take advantage of the interrelations within the ecosystem for the conservation of the soil as a resource and the extended reproduction of the soil fertility. This is only possible, however, when the extraordinary variety of the fertility-determining features of the soil and the dynamics of the processes influencing fertility is recognised and taken into consideration. The representations on soil degradation in this study material, therefore, are preceded by a few Sections on the soil as a resource in the tropics, on the soil fertility and differentiation of features of tropical soils determining the fertility. Because of lacking space it is unfortunately not possible to deal with individual genetic soil types within the scope of this paper.

III.2.1.2. Area potential and soils of the tropics

When considering the two terrestrial latitudes known as tropics as the limits of the Tropics, the mainland situated within this region comprises approximately 5,000 million hectares, these are 37.3 per cent of the ice-free mainland of the earth. The astronomic limitation does not correspond exactly to the climatic, ecological and vegetation-geographic boundaries of the Tropics. For a judgement of the area and production potential of the Tropics, one may start from the regions within the tropics.

Table 1 gives a survey of the important shares of agricultural and forestry areas. With a share of 10 per cent in the total area for the cultivation of annual and perennial cultivated plants, the degree of utilisation of the total area is in the Tropics of the same magnitude as in the world altogether. The proportion of the forest areas rapidly decreases in all continents due to the destructive lumbering and extension of areas for agricultural use. An exact limitation of the grassland

Table III.2.1. - 1: Land-use in the Tropics in million hectares

Region	Total area	Cultivated area under annual and perennial crops	Meadows and pastures	Forests and woods
Tropical America	1,683	83	282	914
Tropical Africa	2,212	166	652	571
Tropical Asia and Pacific Region without Australia	931	256	21	412
The Tropics total	4,826	503	955	1,897
World	13,392	1,424	3,001	4,091

Source: Calculated by Sanchez (1976) on the basis of the FAO Production Yearbook 1970

areas is difficult because there is a continuous transition to the semi-desert and desert regions. It is estimated (Sanchez, 1976) that in the Tropics 1.7oo million hectares can be subjected to arable farming and 1.600 million hectares to pasturing, this would be 66 per cent of the total area. These figures show that the Tropical regions represent a considerable resource for an extensive expansion of the agricultural production. For economic, social and ecologic reasons, the development of this reserve is difficult and can only be effected gradually. The main way of increasing the production in agriculture and forestry is the intensification also in the Tropics. The FAO (1979), in its prognostic document "Agriculture toward 2000", shows a ratio of 72 : 28 between production increase due to intensification and that due to extension of areas. In the Tropics, the extension of areas will certainly play a more important role than in other regions.

Extensive and intensive increase in production are in a close relation with the differentiation of the climatic conditions in the Tropics. The climatic conditions largely determine the growth conditions for the useful plants, and they are also in close relation with the arrangement of the natural forms of vegetation and the development and structure of the soil cover. The decisive differentiating climatic factor is the precipitation regime (mean annual amount of rainfall, precipitation distribution). Table 2 shows a survey of the areas of the major climatic regions. 23 per cent of the total area of the Tropics are highland regions at an altitude of more than 900 m, 3 per cent are situated at an altitude of more than 1,800 m (Sanchez, 1976). Table 3 shows the formation of dry substance in varions vegetation forms.
The decrease within the Propics from the rain forest to the deserts is in essence conditioned by the factor or water.
No limitation by a shortage of water is given on 28 per cent of the area of the Tropics only while on 42 per cent of the area the growth is restricted to 4 to 6 months and on 30 per cent of the area to more than 6 months by drought. The factor of water, however, does exert an influence on the growth of plants not only directly. The thoroughly wetting of the soil is of great importance to the processes of the soil development, especially to chemical weathering, displacement of soluble substances and processes of the new formation of minerals and humic substances. The moisture regime in the soil is naturally closely related to the climate although the surface drainage and the inner draining conditions may considerably vary and differentiate the conditions in particular.
On the basis of the map by Aubert and Tavernier (1972), Sanchez (1976) calculated the following proportions of area of the various soil moisture regions.

Table III.2.1. - 2: Major climatic regions in the Tropics (based on the Landsberg-Troll Classification)

Climatic region	Number of humid months	Predominant vegetation	Area in millions of hectares				Per cent of the Tropics
			tropical America	tropical Africa	tropical Asia	total	
Rainy	9.5 to 12	rain forest and forest	646	197	348	1191	24
Seasonal	4.5 to 9.5	savanna or deciduous forest	802	1144	484	2430	49
Dry	2 to 4.5	thorny shrubs and trees	84	486	201	771	16
Desert	0 to 2	desert and semi-desert scrub	25	304	229	558	11
Total			1557	2131	1262	4950	100

Source: Sanchez 1976

Table III.2.1. - 3: Annual formation of dry substance of various forms of vegetation in tons per hectare

	Mean value	Zone of dispersion
tropical rain forest	20	10 to 35
tropical deciduous forests	15	6 to 35
tropical savannas	7	2 to 20
croplands	6.5	1 to 40
temperate deciduous forests	10	4 to 25
temperate prairies	5	1 to 18

Source: Golley and Leith 1972 Quoted from Sanchez 1976

(continued from page 8)
Udic 29 %
Ustic 34 %
Aridic 29 %
Aquic 8 %

These terms are quoted from the U.S.A. Soil Taxonomy and have the following meaning:

Udic = The control range of the soil profile is dry less than 30 days per year

Ustic = The control range of the soil profile is dry more than 90 cumulative days per year but less than 90 consecutive days and less than 180 cumulative days per year

Aridic = The control range of the soil profile is dry more than 180 days per year, and less than 90 consecutive days days per year it is moist

Aquic = The soil is soaked by moisture to such an extent that reducing conditions may occur

In this connection, "dry" is defined as the decrease of the moisture below the permanent wilting point. The control range of the soil profile is approximately 10 to 30 cm in clay soils, 20 to 60 cm in loam soils, and 30 to 90 cm in sand soils but is defined differently in particular.

The extraordinarily great differentiation of the precipitation regime, of the feed and transformation of organic substances, of the wetting of the soil and the formation of infiltration water cause, in connection with geologic conditions, a pronounced differentiation of the soil cover in the Tropics of practically the same distinctness. The classes or systems of the highest classification levels included in the internationally accepted classification systems are found almost without any exception in the Tropics. Lithotoles, calcimorphous soils, fersiallitic and ferralitic soils are widely distributed.

Table 4 gives a survey of the areas and the proportions of various soils in the Tropics on the basis of the units of the world soil map of the FAO/UNESCO of 1975.

Table III.2.1. - 4: Absolute areas and percentages of the main soil units found in the Tropics (World Soil Map of the FAO/UNESCO)

Soil unit	Absolute area in million hectares	Percentage of the total area of the Tropics
Ferralsole	1050	21
Lithosole	900	18
Acrisole	800	16
Xerosole	400	8
Nitosole	250	5
Yermosole	200	4
Vertisole	200	4
Luvisole	200	4
Gleysole	200	4
Fluvisole	200	4
Andosole	100	2
Cambisole	100	2
Histosole	100	2
Regosole	100	2
Solontschake	40	1
Planosole	70	1
Other soils	100	2

Source: Buringh, 1979

III.2.1.3. Soil fertility - term and definition

Soil fertility is defined as

1. the capability of the soil to satisfy the needs of the plants within the scope of the possibilities given by the other site factors, and that directly or by a reaction to agrotechnical or agrochemical measures promoting plant growth, and
2. the suitability of the soil for the employment of the instruments of production and technologies of production corresponding to the social developmental level of the productive forces.

In addition to the supplier function of the soil for the plant (water, nutriente, oxygen for the roots), the capability of the soil for neutralising toxic substances or pathogenic organismen by sorption processes and biological decomposition may also be included in the soil fertility. Further, it may be justified to consider the capability of the soil to offer resistance to phenomena of degradation as an element of fertility. This shows that the term of soil fertility may be framed more or less widely and, hence, different definitions are proposed.No doubt, the fertility is an objective property of any soil (Marx, Kapital, Vol. III) which characterises the use-value of the soil as a means of production in agriculture and forestry. Although any soil has a "natural" fertility, i.e. a fertility which is idependent of man and the social use of the soil (function of supplying and decontamination), soil fertility is not a purely natural-historical but also a social category. The soil fertility in the sense of the above definition determines to a high degree the applicability of certain methods of production and the attainable labour productivity.The more fertile a soil, the higher the labour productivity is. The soil fertility is an essential determinant of the economic result of land-use in agriculture and forestry. Of particular importance is the fact that more fertile soils not only yield higher crops but also show little yield variations and thus ensure a higher social security of the land user while the expenditures of living and materialised labour remain constant.

Fertility is the property of the soil which is most important to the existence of human society. Due to this fertility, the soil cover of the mainland of the earth becomes the basis of the existence of mankind in the sense of an indispensable precondition for securing nourishment. Until the present, in no historical period mankind succeeded in utilising the soil in such a way that all inhabitants of the earth had enough to eat. Today, the required knowledge of the soils and their fertility - irrespective of all still unsolved problems - and the technological preconditions for ensuring the sufficient feeding of all people are given. A condition would be, however, the ending of the senseless waste of mental and physical powers and of material resources in armament and war as well as the creation of social structures which guarantee employment and sufficient income to everybody.

III. 2.1.4. Fertility-determining features of the soils

The importance of the soil fertility as a measure of the use-value of the soils in agriculture and forestry gives rise to an interest in the quantifying determination of this property of the soil. As to the determination of the soil fertility, two basic statements are of importance:

1. The most reliable method for measuring the soil fertility is the field test conducted over a period of several years. Only the plant mirrors the soil fertility with the required complexity in growth and development.

2. Any measurement of the soil fertility in a field test is related to the complex of the other natural growth-influencing site factors (climate, weather, length of the day, altitude, relief, etc.) and to a certain cultivation technology.

Field tests are expensive and time-consuming. Therefore, time and again, justified attempts were made to derive an opinion on the fertility of the soil from individual properties and features of the latter. The problem associated with this attempt was the fact that, in the last analysis, the soil fertility is the result of the interaction of all biological, mineralogical, chemical, physico-chemical and physical properties of the soil and their dynamic interrelations. The fertility is a summary fucntion of the extraordinarily complex heterogeneous system of soil. The measurement of the fertility on the basis of a single or several features will never give the same information as the plant test. Nevertheless, the determination of individual fertility-determining features is justified, ar that for the following reasons:

1. The ascertainment or determination of individual soil features or properties quicker ana at less expenditure than the vegetation test.
2. The importance of individual soil properties to the soil fertility can be examined in the plant test and evaluation categories can be derived from these plant tests.
3. Not all of the soil properties have the same importance to the fertility. A certain hierarchy of the soil properties can be stated which enable the derivation of important information about the fertility from a relatively small number of qualitatively or quantitatively recorded features.

The judgement of the soil fertility by means of certain morphological or analytical features is always based on the results of a comparison between these features and the information given by the plant test, especially the field test. Since the expenditure involved in a plant test does not permit the conduction of such tests in all sites, the judgement on the basis of fertility-determining soil features is, above all, a means of extrapolation of findings in field tests to larger areas. Thus, it remains to be a question of decisive importance to see to it that any country disposes of a network of field tests conducted over a period of many years each and carried out in properly selected and representative sites and designed on the basis of a pattern which, on the one hand, enables the required comparisons throughout the country in question and, on the other, properly records the specific forms of utilisation and conditions of use of the individual sites.

The soil fertility results from a number of complex properties of the soil. In this connection, it should be pointed out that the resolution of the unity representing the soil into individual elements always is an arbitrary act which shows subjective traits. One may hold the view that the following complex features, however, condition the fertility of the soil:

1. The structure of the solid phase of the soil with respect to substance and space.
2. The cavity system in the soil, its size and structure, determined by the spatial structure of the solid phase.
3. The distribution of the cavities to water and soil-air due to the condition of the cavity system and the substantial nature of the solid phase of the soil, and the motion and bonding of water.
4. The composition and activity of the totality of all living organisms in the soil.
5. The content of plant nutrients in the soil as well as its capability of storing nutrients or to transform them into forms that can be taken in by plants.
6. The soil reaction and the buffering of the latter.
7. The consistence of the soil and its changes in dependence on the water content.
8. The redox conditions.
9. The structure of the profile and the vertical differentiation of the features given in items 1 to 8.

The aim of the judgement of the fertility properties of a soil consists in the acquisition of these complex elements of the fertility behaviour. For this purpose, there are no direct methods. The methods of the morphological judgement and of the analytical studies of soils in essence furnish only partial information about these complexes and it calls for the knowledge and experiences of the expert to interprete these partial information and to integrate them into an overall picture.

III.2.1.5. The degree of leaching and weathering of the soils and soil fertility

In the Tropics soils of an extraordinarily different degree of leaching and weathering are found. The desert soils of the extremely arid climate represent the initial stage of weathering and leaching, while the ferrallitic soils of the humid regions reach the highest degree of leaching and weathering. All intermediate phases are also found in the Trpocis. There are close interrelations between degree of leaching and weathering of the soils and soil fertility which can be traced back to the systematic change of certain fertility-determining features with increasing degree of leaching and weathering. The essential correlations are represented below.

The weathering of the geological initial substrate of the soils begins with the comminution of the magmatic rocks. When leaving out of account the occurrence of volcanic ashes, then the processes of the so-called physical weathering are at the bottom of this fragmentation of the solid rock. With progressing reduction in size of the grain, the specific surface of the geologic materials grows and thus the possibilities of chemical reactions with the constituents of the water and air: the intensity of the chemical weathering increases. With sufficient comminution of the material, the chemical transformations become predominant. Chemical transformations are changes of substance. Checmical weathering causes a change of the chemical and mineral composition of the inorganic soil material.

Leaching is the removal of soluble substances from the soil profile by infiltration water penetrating the subsoil. The formation of infiltration water is due to an ample amount of rainfall. The deeper the soil profile and the greater the water storage capacity of the soil becomes due to clay formation and humus accumulation, the larger the amounts of rainfall required in order to cause the leaching of soluble substances. The removal of soluble substances from the solum causes a change in the composition of the soil material.

There are irrevocable correlations between leaching and chemical weathering. The removal of the soluble weathering products by leaching leads to a disturbance of the chemical equilibria and is a continuous impetus to the chemical weathering. Chemical weathering and leaching must be considered an undivided process from the angle of the soil development. The degree of leaching and weathering of a soil is the extent of the relative change of the chemical, mineralogical and material composition of the soil as compared with the geologic initial material. It should be noted that soils not always develop from magmatic rocks or metamorphic rocks but more frequently from materials which were already transformed and displaced on the surface of the earth, frequently several times in different erosion cycles.

Both consolidated and loose sedimentites already have a certain degree of leaching and weathering before the soil development is started on them.
Leaching and weathering increase with increasing temperature, increasing wetting of the soil and increasing formation of infiltration water. Increasing supply of organic substance

and, consequently, an enhanced biological activity act in this direction. In particular, the causes are as follows:

- the acceleration of chemical reactions with increasing temperature;
- the sustained action of chemical transformations in case of a long duration of soil wetting;
- the increasing dissociation of the water with increasing temperature and thus the increased hydrolysis of the minerals;
- with increased formation of infiltration water, the accentuated disturbance of the chemical equilibrium, removal of even hardly soluble substances (silica) and the accelerated acidification and protolysis;
- when the soil is well wetted through and a high temperature given, a more intensive biodegradation takes place (formation of carbonic acid, formation of organic substances which are capable of bonding metals as chelates, development of low-molecular organic acids).

These correlations entail that, under the conditions of the humid tropical climate, leaching and weathering take a particularly intensive course and soils with an extremely high degree of leaching and weathering occur. The wide distribution of soils with a high degree of leaching and weathering is the peculiarity proper of the Tropics. For a long time, this fact has been considered from one angle only, that is to say, it has been neglected that two thirds of the area of the Tropics are covered with soils having a low to medium degree of leaching and weathering.

The correlation between leaching and weathering degree and fertility of the soil results from the following facts:

1. With the chemical weathering of the primary silicates and other minerals, their constituents are released. These include important plant nutrients (K, Mg, Ca, P, S, micro-nutrients). At first, an intensive chemcial weathering means and increased loss of nutrients. As soon as the reserves of the geological starting material in the form

of primary minerals capable of being weathered are exhausted, the substrate becomes poor in nutrients. This state will occur the quicker, the more rich in quartz the rock is and the more intensive the leaching of soluble products of weathering is.

2. Secondary minerals develop from the products of weathering of the primary minerals and due to the direct transformation of layer silicates. These secondary minerals usually are highly dispersed and are contained in the clay fraction of the soil (particles <2 µm). Increasing leaching and weathering degree, therefore, means an increasing clay content of the soil as a tendency provided comparable geological starting materials were given. The increasing content of clay enhances the surface activity of the soils, a property which is of importance to the sorption of dissolved substances, the humidification, formation of structure, the buffering of the soil reaction, and the concentration of nutrients in the soil solution, the effect of mineral fertilisers, etc.

3. In dependence on the proportions of the weathering products silica, aluminium hydroxide and alkali as well as alkaline earth ions in the soil, different secondary minerals are developed. The proportion of these substances is determined by granularity and composition of the geological parent material, on the intensity of weathering, on the intensity of leaching, on the supply of dissolved substances with later water motion. With a declining basicity and decreasing ratio of silica to aluminium hydroxide, a sequence of different secondary minerals in clay is brought about

   - three-layer minerals
   - two-layer minderals
   - free oxides of aluminium and iron in different states of crystallisation.

With comparable geological parent material, this sequence corresponds to the sequence which develops with increasing degree of leaching and weathering. Soils with a different degree of leaching and weathering show regular differences in the qualitative composition of the clay fraction and, depending on this, differences in the nutrient transformation, formation of structure, accumulation of humus and other properties.

The qualitative composition of the clay fraction is of particular importance to the differences in the fertility properties of tropical soils. The most important differentiating features of the clay constituents are charge properties, specific surface, basicity and swelling ability.

Charge properties

Clay constituents have an electric charge. From this charge, Coulomb forces are emitted, i.e. ions found in the soil solution surrounding the solid particles are attracted or repelled. The clay constituents have different charges both as to magnitude and sign. The following list shows the most important facts:

Clay constituents	Type of charge	Magnitude of the charge	Sign of the charge
Three-layer minerals	mainly permanent	high to very high	negative
Two-layer minerals	mainly variable	low	negative or positive
free oxides - amorphous	exclusively variable	high to very high	negative or positive
- crystalline	exclusively variable	low	negative or positive
Humic substances	exclusively variable	high to very high	negative

The negative charge effects the cation sorption and, thus, the adsorption of cationic nutrients (K^+, NH_4^+, Ca^{2+}, Mg^{2+} etc.) which is important to the nutrient content but also to the buffering of the soil reaction against acidifying influences. Positively charged clay constituents are the carriers of the anion sorption. Remarkable positive charges possess in the soil especially the free oxides and the kaolinitic minerals whose charge is variable. A variable charge is the essentially pH-dependent charge of clay constituents which is brought about by an addition or dissociation of H^+ and OH^+ ions. Below the isoelelctric point, the charge is positive and negative above it. Minerals of the kaolinitic group and free oxides are brought about in larger quantities only in case of advanced leaching and weathering in a more or less acid environment. Under the conditions of an acid environment, their charge is mainly positive. The kaolinitic minerals and especially the free oxides of aluminium and iron are the basis of the anion sorption. The cation sorption in oxidic soils, i.e. in soils having a high degree of leaching and weathering, is exclusively ensured by the negative charge of the organic substance. This increases the importance of the humus content of these soils.

Specific surface

Although all secondary clay minerals are reckoned among the highly disperse soil constituents, they are nevertheless distinguished by their degree of dispersion and thus by their specific surface and, hence, by their reactive power. The minerals of the montmorillonite group excel in a particularly fine granulation size. They are mainly found in fine clay ($< 0.2\,\mu m$). Kaolinite usually is coarser and is mainly found in coarse and medium clays.

Illites frequently develop by a progressing grain comminution of the primary micas and can occur in different granulation sizes but mainly have diameters which are between those of montmorillonite and kaolinite. A very large specific surface is characteristic of amorphous free oxides with a sponge-like structure. The specific surfaces of the crystalline oxides usually is smaller than that of the amorphous forms and, in particular, depends on the crystallisation conditions and varies within wide limits.

The importance of the specific surface consists in its influence on the charge density and thus on the strength of the bond of adsorbed ions, and in the action of the formation of structure by cohesive forces. With the same electric charge, the charge density drops with increasing specific surface. With the charge density, the strength of the ionic linkage decreases and in this manner the selectivity of the ion adsorption from the polyionic soil solution also changes. The bond or linkage forces between clay particles are of great importance to the formation of structure and the consistence of the soil. The finer the particles, the greater the surace forces which connect them into a compact mass or aggregates. Soils with a great content of montmorillonitic clay in a dry state have a high hardness whereas kaolinitic soils with the same clay content are brittle and show a lower cohesion.
In this connection it is of importance to note that with increasing specific surface the capability of an addition of water also increases. Water envelopes separate the individual clay particles so that they can be displaced relative to each other. With increasing dispersion of the clay particles, the plasticity of the wetted soil increases. The high surface activity of amorphous oxides and also of humic substances is the cause of their suitability as a cementing substance in the formation of aggregates.

Swelling and shrinking

Various three-layer minerals, especially minerals of the montmorillonite groupe, possess the capability of swelling and shrinking. Swelling and shrinking are expressions of changing water contents. The capability of a addition of large amounts of water to the external and internal surfaces of these minerals is due to the fine granulation size and to the diminished coherence of the elementary layers of the silicate particles due to an expansion of the basis distance to 1.4 nm and more. The reduced coherence of layers permits water molecules to enter into the interspaces between the layers and to further enlarge the basis spacing, hence, the mineral particle swells. When drying up, this water is withdrawn, the basis spacing is reduced and the mineral shrinks. The swelling and shrinking behaviour is not determined by the structure and surface forces of the mineral but also by the type of adsorbing ions. Adsorbed sodium ions are inducive to swelling because of their hydration whereas calcium ions damp this process.

The practical importance of swelling and shrinking consists in the fact that minerals capable of swelling in soils with a sufficiently high clay content cause these soils to become self-structuring. Volume reduction of a continuous soil mass due to drying leads to the formation of shrinkage cracks by which the soil body is divided into aggregates. Within the aggregates forces of cohesion cause coherence. Typical representatives of soils calable of swelling are the vertisols in the Tropics. In contrast to the soils with three-layer minerals, especially to the montmorillonitic soils, the kaolinitic and oxidic soils are not capable of swelling.

Base content

Clay constituents exert an influence on the nutrient supply of the soil not only because of the storage and fixing of ions depending on charge and surface structure but also because of their own nutritive content. In the form of the so-called intermediate-layer ions, which ensure the coherence of the silicate layers, three-layer minerals contain larger amounts of the nutrients of potassium, magnesium and calcium. Upon weathering of the three-layer clay minerals, these nutrients are released and can be utilised by the plants. Due to the conditions of their formation and structural properties, nor the minerals of the kaolinitic group nor the free oxides of aluminium, iron and manganese contain considerable amounts of nutrients.

It has already been said that the qualitative composition of the clay fractions changes with increasing degree of leaching and weathering. In case of a low degree of leaching and weathering, three-layer minerals are the dominating clay constituents. With increasing degree of leaching and weathering, these minerals are replaced first by intermediate layer minerals and finally bx oxides. From the properties of the clay constituents the following changes of the fertility behaviour are derived with increasing degree of leaching and weathering:

1. The capability of storing cations decreases. At the same time, the cation adsorption - due to the increasing role of the organic substance as carrier of the negative charge - increasingly becomes pH-dependent. The risk of the leaching of cationic nutrients and insufficient supply of these nutrients to plants increases.
2. The anion sorption increases. Due to the fluid transitions between exchangeable (non-specific) and specific bond of phosphate ions, with the increasing content of free oxides in the clay fraction, the phosphate fixing in the form of iron and aluminium phosphates also increases.
3. The decreasing base content or basicity and the decreasing cation exchange capacity impair the preconditions for the

formation of permanent humus (grey and brown humic acids) and for the stabilisation of humus in the form of clay-humus complexes.

4. The nutrient content of the clay fraction decreases.
5. The capability of the soil for stabilising the soil reaction (buffering) is reduced.
6. The structure-forming processes and the structure properties are changed. In soils rich in clay, separation structures and humus-bonded building-up structures are increasingly replaced by kaolinitic coherent structures or structures of oxide-bonded aggregates of a high stability. The structural properties of the soils show a trend towards improvement.

The change in the fertility properties of the soils with increasing degree of leaching and weathering is, first and foremost, but not exclusively a consequence of the changes in the composition of the clay fraction. Added to the qualitative effects caused by the clay fraction are the systematic impoverishment of minerals that are subject to weathering in the coarser fractions of the soil, the increasing acidification, the danger of the occurrence of toxic concentrations of manganese and aluminion ions, the changed conditions for the transformation of organic substances, etc. It should be stressed, however, that the represented relations between degree of leaching and weathering of the soil and the fertility properties only express the basic trend which facilitates the understanding of the systematic changes of the fertility features of soils from the arid regions to the alternatingly moist tropics and through to the humid regions. In particular, the fertility may show considerable deviations due to peculiarities of the geologic parent material, drainage conditions and the addition of foreign matter. It should be pointed out to the fact that substrates with a high content of quartz result in sandy soils (regosols, arenosols) in which the differences in fertility depending on the degree of leaching and weathering are less distinct than in soils with a high clay content.

For the determination and judgement of the degree of leaching and weathering, the following features can be used:

1. pH and degree of base saturation
2. SiO_2/R_2O_3 ration and SiO_2/Al_2O_3 ration of the soil or of the clay fraction
3. Ratio of silt : clay
4. Content of weathered minerals in the soil.

III. 2.1.6. Soil degradation

III. 2.1.6.1. Term and importance

During the past decades, scientists and politicians -induced by the rapid growth of the world's population and attempts of estimating the global production potential for foods - increasingly became aware of the fact that the world soil resources are not only limited but absolutely reduced by improper use of the soil and processes of soil destruction. This was expressed in the recommendation by the world food conference of the FAO in 1974 to elaborate a world soil charter whose text was confirmed at the 21st session of the FAO conference in November 1981. At the same time, the project of a world soil policy and a detailed plan for its implementation were elaborated (UNEP, Nairobi 1982) within the scope of the United Nations Environment Programme (UNEP).

That part of the soil cover of the world which is suited for agricultural use because of its nature amounts to 5 to 6 thousand million hectares. This area is not really available, however. It is considerably reduced by urbanisation, industrialisation, construction of roads and processes of soil destruction. Although such estimates naturally are subject to uncertainties, one assumes that in historical time about 2 thousand million hectares of potentially agriculturally usable land have been lost due to these processes (Kovda, 1981). The decisive topical problem, however, is the continuously increasing extent of land losses during the 2nd half of the 20th century. Estimates on the basis of the recent trends have led to the result that land losses to the tune of 0.2 to 0.8 thousand million hectares have to be reckoned with in the forthcoming 20 to 30 years.

From analyses by various authors (Prassolov and Rosov, 1947; Revelle, 1976; Rosov and Obodovskaja, 1978) it becomes obvious that a fund of land potentially usable by agriculture of 2.7 to 3.6 thousand million hectares is available of which 1.5 thousand million hectares are already subject to arable farming. The available resources are unequally distributed to the continents(Fig.III.2.-1.)When the prevailing trends continue to act in the development of losses of potentially arable land by the above mentioned processes, the situation illustrated in Fig. 2 may occour. Taking into consideration the growth of the world population, a considerably decrease in the arable land per head of the population would be the result. Fig.III.2.-2. clearly shows that even considerable increases in yield on the remaining areas of arable land cannot compensate the effects of the land losses. Further, the experiences gathered during the "campaign against hunger" carried out by the FAO during the seventies show that under the present politica, social and economic conditions in numerous countries a rapid doubling or even quadrupling of the yields within the scope of a country is practically not attainable, as postulated by Meadows et al. (1972) in Fig.III.2.-2.

From these facts and correlations, the imperative necessity results that we have to change our views radically with respect

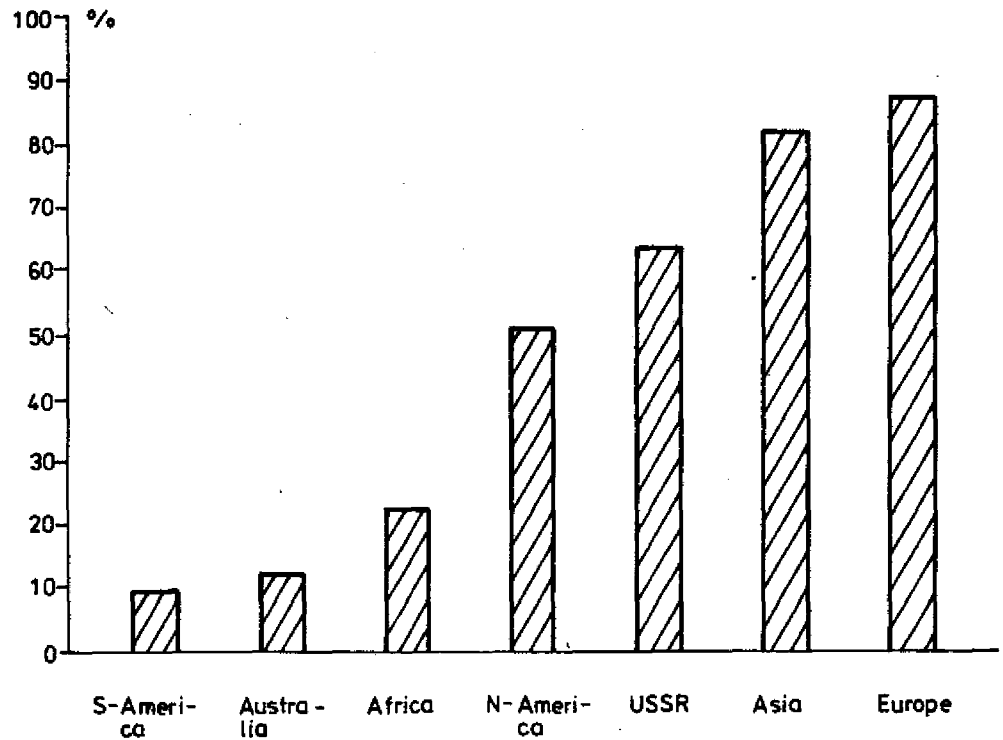

Fig. III.2.-1.
Utilisation of areas suitable for arable farming in per cent in various regions (after Hopper, 1976)

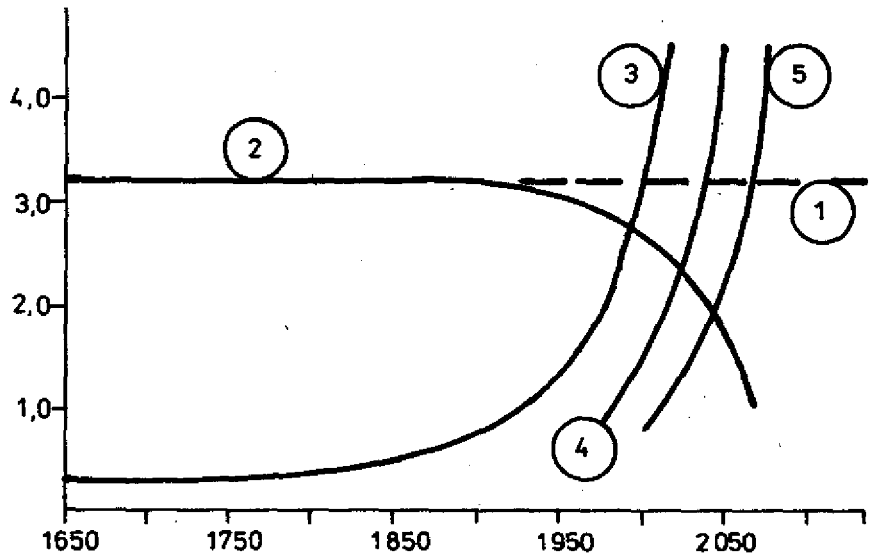

Fig. III.2.-2.

Fig. 2 Development of the available arable land and of the demand for arable land (after Meadows et. al., 1972)

① present potential arable land
② de facto remaining arable land
③ demand for arable land related to the yield level of 1970
④ demand for arable land when yields are doubled
⑤ demand for arable land when yields are quadroupled

to the handling of the fund of land. Everything depends on maintaining a maximum of area under a vegetation cover and to counteract all sources of losses of agriculturally usable land. It should be taken into consideration that loss of soil not only covers the cultivated but wrongly utilised areas or the areas completely devastated by erosion but that the lingering reduction of soil fertility is tantamount to a loss of a production potential based on the soil and, hence, practically to a loss of soil. The solution of this task of an effective struggle against soil losses and for a reasonable utilisation of the fund of land in both national and global scope within the shortest possible time has become a question of existence of mankind. The slogan "save the soil (Kanwar, 1982; Singh, 1982) formulated several times at the 12th congress of the international soil science society in New Delhi in February 1982 has its profound justification.

The struggle against soil degradation in the land used by agriculture and forestry has become one of the most decisive tasks of world soil policy in addition to a sensible utilisation of land.

The term soil degradation has not been used uniformly until the present. Neef (1975) defines, from the angle of geography, degradation as the partial or complete loss of characteristic features of a soil. Such changes can be effected by a change of the climate, by geological and geomorphological processes but also be intervention of man into the structure of a biogeocoenosis. In many cases, the soil is changed indirectly by variation of the effect of individual or several factors influencing the soil development (vegetation, water supply, temperature regime, etc.). In the course of the land-use by man, direct interventions such as loosening the soil, pressure on the soil by machines, irrigation and drainage, chemical amelioration and similar actions may also lead to degradation.

A soil degradation in the sense of a change in the direction of the pedogenesis must not necessarily include a reduction of the fertility of the soil. The term "soil degradation" may be used in a narrower sense from the angle of agriculture and forestry and, in this connection, always expresses a reduction of the soil fertility caused directly by the land-use for purposes of production or by indirect influences exerted by human society on the biogeocenosis. In agreement with the UNEP-Document on the world soil policy (UNEP, 1982) and its definition of the term of soil degradation, i.e. the reduction of the soil fertility inadvertently caused by man, we shall deal with this problem below.

Different processes may take part in the soil degradation in the sense of an anthropogenetically caused decrease in fertility. The most important of them are:

1. Secondary salinisation of irrigated areas in dry regions
2. Accelerated soil erosion
3. Secondary soil acidification
4. Degradation of structure
5. Loss of nutrients
6. Petrification

III.2.1.6.2. <u>Secondary salinisation of soils in arid regions</u>

(1) <u>Term and definition</u>

The term "secondary salinisation" subsumes all phenomena of the occurrence of increased salt concentrations in the soil solution or increased alkalinity of the soil which are caused by the activities of man. With this, a delimitation from the primary salinisation is effected which is defined as the natural development of salt soils (halomorphic soils) in sites suited for this. In contrast to the gradual natural salinisation which leads to the characteristic morphologic features of salt soils (solontchak , solonetz), the secondary salinisation in general develops relatively quickly. Therefore, the morphologic features of salinisation are missing in most cases of secondary salinisation. The high salt concentration of the soil solution and the highly alkaline pH value of the soil, which is due to the presence of soda (Na_2CO_3) and/or a high sodium saturation of the sorption complex of the soil, are given and effective.

The secondary salinisation leads to an impairment of growth and development of the plants. There are no basic differences with respect to the causes of this impairment between the primary salt soils and the secondary salinisation. Both the osmotic total potential and the disturbed ion ratios in the soil solution and the deterioration of the soil structure due to the pH and the high sodium saturation of the sorption complex are effective. Injuries to plants are caused above all in sensitive species and in the seedling stage. Usually, they occur not on larger areas in an uninterrupted manner but in the form of smaller spots, special portions having an increased micro-relief. With increasing secondary salinisation it may happen that even species tolerating salt fail to grow or no longer show yields which justify cultivation so that larger areas must be omitted from utilisation or ameliorated.

(2) Causes and effects

The secondary salinisation primarily is a phenomenon of the arid regions and associated with interventions in the water supply of the site in connection with irrigation of cultivated plants. The effective salts (chlorides, sulphates, carbonates, and bicarbonates as well as nitrates of the alkali metals and alkaline-earth metals Na, K, Mg, Ca) stem from magmatic rocks in the final analysis (except for the nitrates) and they are released when these rock weather. In most cases of secondary salinisation, these salts were already present in the landscape before damage due to salts occurred, namely, in the subsoil as constituents of sediments or dissolved in the ground water. A special case are phenomena of salinisation close by the coasts of seas or oceans. Salts from the sea water are blown by winds up country in the form of aerosol or by water intrusion into the underground of the soils. The penetration of sea water into the underground is favoured by pumping off the water of the salt-free ground water for irrigation (example: growing of citrus and vegetables in the coastal areas of the isle of Cyprus). Damage due to salt in the vicinity of salt deposits, salt mines and industrial plants emitting salty sewage must be considered special cases.

In the typical cases of a secondary salinisation of arable land, the activation of the salts present in the landscape and their concentration in the rooted range of the soil is effected by irrigation, i.e. by changes in the supply of water. Two basic situations causing salinisation must be distinguished: Secondary salinisation due to a rise of the ground water level and secondary salinisation due to sustained use of salty irrigation water.

Secondary salinisation due to a rise of the ground water level

In the irrigation of agricultural areas in arid regions, mainly methods of surface irrigation (basin, strip, furrow irrigation) are used. These methods and the feed of water to the tapping points in ditches are associated with a non-productive oozing away of considerable amounts of water into the underground. This oozing away is the greater, the more imperfect the installation and operation of such irrigation systems is. Particularly high amounts of seepage water occur frequently when irrigation is carried out once for the purpose of storing water in times when an ample supply of water is available, i.e. when one need not be sparing of water. In case of a good technological performance of irrigation, an average efficiency of 60 per cent can be attained in surface irrigation (Israelsen and Hansen, 1962). According to Kovda (1981), the majority of systems for surface irrigation only attain efficiencies between 30 and 40 per cent. About 50 to 60 per cent of the fed water can be lost by seepage through not properly sealed water conduits. These data show the magnitude of water passing into the subsoil which is possible in surface irrigation. If, due to stratification and inclination of rock conducting water close by the ground surface a vertical or lateral drainage of water is not possible, then the ground water level will be raised mor or less quickly. This rise of the ground water level may be several metres in a year in unfavourable cases (Kovda, 1981). In the Indian and Pakistan Punjab, it was 30 to 50 cm per year after the construction of new irrigation systems at the beginning of the 20th century (Young, 1976). As soon as the capillary margin above the ground water reaches the root-containing part of the solum or even the surface of the ground, the evapotranspiration rises by leaps and bounds and an ascending capillary water motion takes place. If this will not equalise the rise of the ground water level, then the ground water will appear in depressions and swamp formation in the relief depressions occurs, a phenomenon which can be observed frequently in a system with surface irrigation which also may lead to losses of agricultural land.

In the arid regions, the ground waters are usually more or less mineralised. The rise of the ground water and the associated increased ascending motion of the water lead inevitably to a transport of salt in the direction of the ground surface. Due to the intensive evaporation of the water, a systematic salt accumulation takes place in the solum and it is only a question of time when reductions in yield and direct injuries due to salt occur in the plants.

Secondary salinisation due to the use of salty water for irrigation

The missing leaching of soluble matter in the landscapes of the arid regions results in the fact that most of the available waters, with the exception of the rivers coming from more humid regions, contain salt to a certain degree. The water shortage necessitates the use of such mineralsied waters for irrigation pruposes. Under these conditions, there is a great risk of secondary salinisation - provided there is a low ground water level and a free internal drainage - when using irrigation methods of a high efficiency such as spray or sprinkler irrigation. The irrigation standards of these methóds are calculated for the wetting of the zone of roots and can be realised exactly. The missing seepage water formation ensures that the whole amount of salt fed together with the irrigation water remains in the solum and that, from irrigation action to irrigation action, a systematic accumulation of soluble salts occurs. The higher the salt content of the irrigation water, the higher the amount of water fed, the quicker the salt content in the solum will exceed the critical limit. Irrigation methods with associated formation of seepage water formation causes the leaching of a part of the fed salts into the underground and, as long as there is no rise of the ground water level, the risk of a secondary salinisation is smaller with this method.

The effects of the secondary salinisation depend on amount and type of the accumulating salts. According to the type of the accumulated salts, a distinction is made between the following main types of secondary salinisation:

soda salinisation
soda / sulphate salinisation
sulphate / chloride salinisation
chloride salinisation

The decisive effect of the secondary salinisation emanates from the change in the osmotic potential of the soil solution. In the event of high osmotic pressures of the soil solution, the useful plants are no longer in a position to take up sufficient amounts of water. At the same time, the normal intake of nutrients is distubred.

If, in the course of secondary salinisation, the ratio of sodium to potassium plus magnesium is changed in such a manner that sodium distinctly prevails, or if the sodium replacement is favoured by the presence of soda (high pH), then the sodium saturation of the sorption complex increases and a dispersion of the clay may take place. The dispersion of the clay effects the collapse of the soil structure: the soil becomes compact and impermeable and its inclination to an incrustation of the surface increases rapidly. The hydrolysis of the sodium-saturated clay usually causes a high rise of the pH value at the same time;that is why this is also called " secondary alkalinisation".

(3) Distribution

Due to secondary salinisation, many millions of hectares of efficient irrigated arable land were transformed into salt deserts and saline soils of a low fertility. The majority of countries with irrigated agriculture in regions with small rainfall are faced with the problem of secondary salinisation. Large land losses due to this form of soil degradation were recorded in India, Pakistan, Iran, Iraq, Argentinia, for example. Exact data of the extent of the secondary salinisation are not available. Estimates show that 50 to 60 million hectares of irrigated arable land are subject to secondary salinisatinn and every year 0.2 to 0.3 million hectares must be excluded from utilisation because of heavy salinisation (Kovka, 1981).

According to Schechter (1976), the share of areas subject to secondary salinisation in the total irrigated area amounted to more than 50 % in Iran, to 25 to 50 % in Syrai, to 33 % in Peru, to 30 to 30 % in Iraq, to 20 % in China and to 15 % in India.

(4) Control

The central problem of prevention and abolition of phenomena of secondary salinisation is the removal of an excessive supply of water with the salts contained in it through a natural or artificial system of drainage. In regions where a risk of secondary salinisation is given, the construction of a drainage system is an indispensable part of the arrangement of areas for irrigation, irrespective of the method of irrigation to be applied.

The drainage system fulfils two tasks:

1. It prevents the rise of the ground water level over the critical minimum depth of 1.5 to 2.5 m.
2. It enables the draining of saline seepage water in case of leaching of salt from the soil.

The results practically reached by means of drainage systems in any case justify the expeditures. Systems of horizontal drainage have proved successful and also thos of a vertical drainage. Horizontal drainage usually is achieved by means of open ditches. A disadvantage of open ditches is the large area required when then the bottom of the ditches is deep, the danger of weed infestation and overgrowth in regions with heavy wind erosion. Vertical drainage with deep wells does not show these disadvantages but it calls for the erection and continuous operation of pumps. The decision on the type of the most effective drainage system is dependent on the site and on considerations of farm management. An essential question of drainage is the disposal of the water involved.

In any case it must be prevented that the evacuated salts cause damage in any other place. When discharging mineralised waters into salt-free rivers and lakes, particular care must be taken because severe disturbances may be caused in these ecosystems. Slightly saline water can be sued for irrigation directly or after mixing with salt-free water.

The gradual accumulation of salt in the rooted part of the soil profile when using water-saving irrigation methods (spray and sprinkler irrigation) calls for the leaching of the accumulated salts. Different methods may be used for this purpose:

1. Leaching the salts at larger intervals depending on the speed of the salt accumulation.
2. Increase of the individually applied amounts of water up to the formation of an amount of seepage water which will suffice to keep the salt content in the root layer of the soil below the critical level.

In case of water shortage it should be noted that repeated application of smaller amounts of water with a lower amount of seepage water formation produce a better salt leaching effect than a larger amount of water applied at a time.

The leaching requirement is the amount of water which must be applied in an irrigation system and with a given quality of water in addition to the water required by the plants in order to keep the salt concentration below the critical value.

The exact determination of this amount of water is difficult. It first calls for the ascertainment of the critical salt content of the soil solution first which must not be exceeded. This critical salt content is dependent

- on the type of salinisation of the water used
- on the texture of the soil
- on the susceptibility of the plants grown.

The leaching requirement for maintaining the desired salt concentration in the soil is also influenced by the irrigation intervals, the intensity of evaporation, and the internal drainage of the soil. Since in most cases a certain horizontal heterogeneity of the physical soil properties on irrigated fields must be taken into account, which influences the leaching of salt in its effectiveness, this fact must be taken into consideration when fixing the irrigation standards.

The general shortage of water in the arid regions also calls for thriftiness in the use of water for leaching salt. The salt content of the soil should not be lowered more than required by the cultivation of the desired plants and by the conditions of the given site. By means of various additional agronomic measures (levelling the fields, planting on the slopes of dams between irrigation furrows, sufficient fertilisation, choice of favourable sowing and planting times), the effectiveness of present salts can be further restricted or the critical salt content can be fixed at a higher level.

The quality of the water to be used for irrigation is of decisive importance to the judgement of the danger of the occurrence of a secondary salinisation. The criteria for an evaluation of the water for irrigation are:

- total salt content
- ratio of sodium to alkaline-earth ions
- residual sodium carbonate
- soda content
- content of toxically acting ions (chlorine, boron, etc.)

Systems of evaluating the quality of irrigation water

When evaluating the quality of the irrigation water according to the specified criteria, various circumstances should be taken into consideration. First, the fact is of importance that the quality especially of surface waters is subject to temporary variations, depending on different factors especially climatic influences. In addition, the negative effect of the salt content in irrigation water on soil properties and plant growth is depending on the soil, the irrigation regime, cultivated plants and cultivation technolgoy. Soils with a constant texture, for example, are less endangered than clayey soils. A schematic application of any classification systems may lead to aggravating faults. The quality yardsticks should always be adapted to the local conditions.

In the evaluation of the quality of water with respect to its use for irrigation purposes, frequently several of the possible criteria are combined. A classical example is the irrigation scheme of the US Salinity Laboratory in Riverside of 1954 which combines salt content and SAR value into a system comprising 16 quality classes (Fig.III.2.-3.). This system has been widely accepted but overrates the danger of salt in many cases. Kanwar (1961) supplemented the system in accordance with the conditions prevailing in North-west India by introducing a class C 5 with a conductivity range of 5 - 20 μmho/cm and taking into consideration both the soil texture and the salt tolerance of plants (cf. Table 5). Of the numerous systems in use, only the system propsed by Doneen (1975) will be underlined here. It evaluates irrigation water with particular reference to salt content and sodium replacement, especially also with respect to the danger of a deterioration of structure and decrease in permeability. For a potential salinisation, the maximum possible precipitation processes are taken as a basis, i.e. only $MgSO_4$ and all chlorides are considered a potential danger. Supposing that 50 % of the sulphate ions are precipitated as gypsum, Doneen calculates the potential

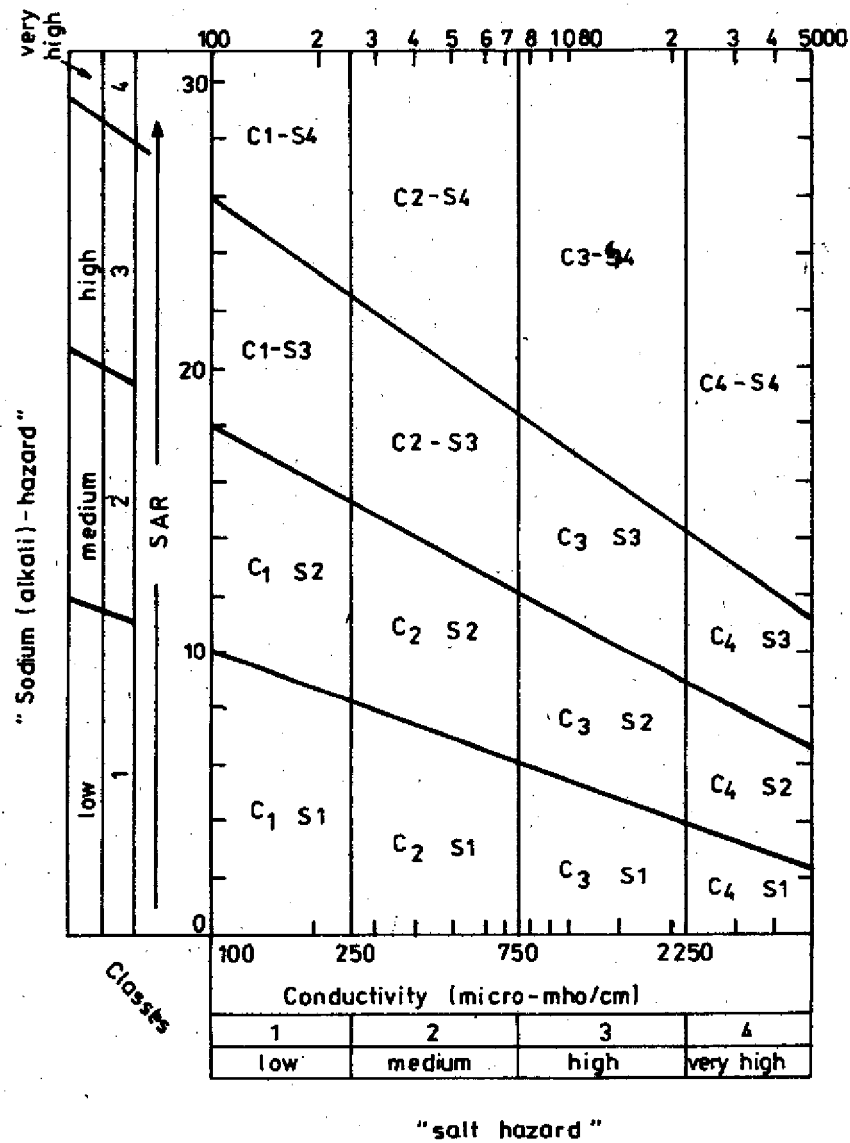

Fig. III.2.-3.
Schematic representation on the evaluation of the quality of the irrigation water of the US-Salinity Laboratory Riverside (Richards, L.A., 1954)

salinity as $Cl^- + {}^1/_2\ SO_4^{2-}$ in mval/l. The permeability index (PI) empirically derived from lysimeter tests is derived from sodium and bicarbonate ion concentration according to the formula

$$PI = \frac{Na^+ + \sqrt{HCO_3^-}}{Ca^{2+} + Mg^{2+} + Na^+} \times 100 \text{ mval/l}$$

For three soil categories with a different initial permeability, the system results in three quality classes each of the irrigation water.

Table III.2.1. - 5: Evaluation of irrigation water according to Kanwar (1961) further developing the scheme given in Fig.III.2.-3.

Texture	Limits of application for		
	sensitive crops	moderately tolerant crops	tolerant crops
Clay	S_1C_2 - - -	S_1C_3 S_2C_1 - -	S_1C_4 S_2C_2 - -
Loam	S_1C_2 S_2C_1 - -	S_1C_3 S_2C_2 S_3C_1 -	S_1C_4 S_2C_3 S_3C_2 -
Sandy loam	S_1C_2 - 5 S_2C_1 - 5 S_3C_1 -	S_1C_3 - 5 S_2C_2 - 5 S_3C_1 - 5 -	S_1C_4 - 5 S_2C_3 - 5 S_3C_2 - 5 -
Sand	S_1C_3 S_2C_2 S_3C_1 -	S_1C_4 S_2C_3 S_3C_2 S_4C_1	S_1C_5 S_2C_4 S_3C_3 S_4C_2

III. 2.1.6.3. Water and wind erosion

(1) Accelerated soil erosion - term and definition and importance

Erosion is defined as the lateral displacement on the surface of the earth of loose material caused by the weathering of rock. Geomorphologically, the importance of erosion consists in the levelling of relief differences caused by it. Both the rock detritus (regolith) and the soils are subjected to the processes of discplacement.

The genesis of the soils is influenced by erosion due to the tapering of the profiles at the place of eroding and by a supply of foreign material (mineralogical, in the granulation) within the range of sedimentation. These two facts are closely correlated with soil fertility.

Erosion is a transport of masses which consumes energy. The sources of energy are the kinetic energy of the raindrops and of the surface flow, the kinetic energy of the wind and gravitation. Erosin by water and wind are only possible because of the global circulation process of water and air and, in the final analysis, a consequence of the supply of solar energy of radiation. Landslips on slopes are possible without energy supplied by wind and water because of the direct action of gravitation.

Erosion by water and wind are natural processes which act on the surface of the earth since mainland has been in existence. Only part of these processes of displacement should be included in the phenomenaof soil degradation, namely, the so-called anthropogenic or accelerated soil erosion. The soil cover of the continents develops from the geologic parent substrate only in close correlation with the biosphere, especially the vegetation. With progressing development of the soil, i.e. with increasing thickness of the profile, horizon differentiation and leaching of detachable constituents, the vegetation cover on the soil also becomes denser, richer in mass and more differentiated. In connection with this, its influence on the development of the soil and the properties of the soil grows and also its capability of stabilising the soil and protect it from the actions of the energy inducing erosion. The survey given on the following page summarises the protective actions of the vegetation for the soil.

Man causes changes in the natural vegetation cover, including even the complete removal of the latter, by measures for procuring food and raw materials and construction activities. Any change in the vegetation cover also means a change in its protective effect. As a rule, it is diminished due to the intervention by man and in a few cases only, e.g. the introduction of irrigation in arid regions with poor vegetation, the situation is improved. Changes in the vegetation cover usually permits a more intensive action of the energy of water and wind on the soil and thus an increased destruction of aggregates and displacement of masses. In many cases, these effects act parallelly to a decrease in the resistivity of the soil against phenomena of soil removal due to humus disintegration, soil compaction, aggregate destruction by mechanical action, increasing tendency to incrustation and other factors which are involved in arable farming and in extensive pasturing. Therefore, in the course of the activities of man, the intensity of soil displacement increases by leaps and bounds due to the action of water and wind, i.e. an "accelerated soil erosion" takes place.

The importance of the accelerated soil erosion results from three aspects

- the severity and great variety of the damages caused
- the irreversibility of the damages to the soil
- the distribution of the phenomenon.

Survey. Aspects of the protective action of the vegetation cover against soil erosion

Erosion by water	Erosion by wind
1. Absorption of the kinetic energy of striking raindrops	1. Absorption of the kinetic energy of the wind close by the surface
2. Interception of a part of the precipitations which evaporate directly from the overground plant parts	2. Interruption of the soil creeping and the saltation motion
3. Slowing down the surface drainage by increasing the roughness of the surface	3. Slowing down the wind close by the surface by friction
4. Protection of the soil from directly striking of drops against the soil by means of litter	4. Separation of the air current from the surface of the soil by litter and the living plant cover
5. Stabilisation of the soil by increasing the content of humus and interlacing the aggregates and particles by roots	5. Stabilisation of the soil by increasing the humus content and interlacing the aggregates and particles by roots
6. Increasing the permeability of the soil (biopores, humus-bonded aggregates) and consequently reduction of the drainage rate	

By the accelerated erosion, a partial or total removal of the formed soil material is effected. Consequently, the soil as the main means of production of agriculture and basis for nourishing mankind is lost or its fertility and serviceability are considerably restricted. In particular, the following damages occur due to accelerated soil erosion in agriculture and forestry:

1. Reduction of the soil fertility by a selective removal of the soil colloids, i.e. the carriers of the sorption capability of the soil in sheet erosion and layer erosion. As a consequence, the content of nutrients and the storage capability of the soil for water and nutrients decreases. The structure of the soil deteriorates and, in connection with this, frequently the water and air supply of the soil and its technological properties.

2. Restriction of the usable soil surface and of possibilities of operation of means of mechanisation by linear forms of water erosion (erosion ditches and furrows). In extreme cases, the linear forms of erosion show a density and intensity which lead to the complete destruction of continuous areas and the so-called bad lands are brought about.

3. Releasing and exposing the root system of plants until they die by tilting over or drying up. These phenomena can be observed both in annual field crops and in trees.

4. Reduction of the assimilation by the deposition of dust on green plant parts in case of wind erosion and, consequently, yield losses.

5. Abrasion by particles carried by the wind caused on overground plant parts; this leads to yield losses and reduced proceeds due to damage to the crop harvested.

6. Superposition of field crops and soils within the sedimentation range. In case of intensive linear water erosion, frequently not only the soil is removed but also sterile stony underground material and sedimentation fans of material of restricted fertility are formed on fertile soils.

7. Reduction of the average yields and increase of the uncertainty of yields, that is to say, increasing insecurity of the existence of the rural population.

While the direct injuries to the growing plant stands only impair the yield of this particular crop and do not cause any permanent effect, any damage to the soil cannot be corrected by economically justifiable expenditure, i.e. it is irreversible. From this follows that the prophylactic control of the accelerated soil erosion is the only possible principle.

The effects of the accelerated soil erosion are not restricted to agriculture and forestry but reach far beyond this scope. The consequences for the water resources are aggravating since the tendency to increase the rates of drainage, which is a consequence of soil destruction and the removal of the natural vegetation, is pronounced in this way. Some of the damages caused beyond the scope of agriculture and forestry are

- intensification of the danger of floods,
- intensive processes of sedimentation in reservoirs and other barrages
- impairment of fishing in waters due to excessive suspended matter and eutrophication
- impairment of traffic in waters because of quite different water levels and intensive sedimentation and displacement processes in navigable flowing waters

- superposition and destruction of communications due to sedimentation and linear erosion
- whole landscapes are turned into arid regions
- deterioration of the general living conditions of man by molestation by dust, loss of vegetation areas and the like.

The extent of the areas subject to accelerated soil erosion can hardly be estimated because damage caused by lingering sheet erosion oab hardly be diagnosed and reductions in yield are already present when soil morphological changes are not yet distinct. Further, the degree of an impairment of an area by linear erosion is not quantifiable without any difficulty because the effects exceed the direct loss of soil and are dependent on the technology of land-use.

Irrespective of these methodical difficulties the fact is given that the accelerated soil erosion represents that form of soil degradation which is most widely distributed and shows a disastrous extent as to the areas concerned and intensity. Estimates of the global damage due to erosion indicate that the annual absolute soil losses due to erosion amount to 4 to 7 million hectares (Singh, 1981). By far greater is the area which is subject to the lingering partial loss of fertility due to erosion.

Regionally, especially the arid regions and the humid Tropics are subject to the accelerated soil erosion. The causes are quite different. Arid regions are endagered especially because of the incomplete cover by vegetation due to water shortage. Intensive wind erosion does not only occur but also considerable water erosion because of high drainage rates during heavy rainfall. The causes of the intensive processes involved in accelerated soil erosion in the humid Tropics are first and foremost a question of the precipitation regime. High mean annual precipitations and high precipitation intensities cause an increased energy input to the ecosystems and, thus, an increased potential danger of erosion which will take effect immediately when man intervenes with the natural equilibrium by destruction of the vegetation. Added to this are the considerable rates of surface drainage in case of high mean annual precipitations and the associated intensification of the soil erosion by flowing water. In the alternating humid regions with droughts of more than 3 months, the reduced protective effect of the vegetation during the drought is a fact that also favours erosion.

(2) <u>Accelerated soil erosion in case of extensive pasture farming</u>

Of the mainland area of the earth, 2 to 2.5 thousand million hectares are covered with different grassland formations. For the greater part, especially in the arid and partly alternating humid regions, these vegetation societies represent the natural climax vegetation, sometimes these are anthropogenetic pseudo-climax conditions which are only maintained by the continuous intervention by man (grass burning, intensive pasturing, mechanical and chemical control of the woods). The major part of the grassland of the Tropics and Subtropics is utilised in the form of an extensive pasture farming, that is to say, by nomadic or semi-nomadic animal husbandry. In association with this form of land-use, disastrous damage has been caused in wide regions of Africa, Australia and South America due to accelerated soil erosion by wind and water.

The cardinal problem of erosion control in grassland is the reduction or elimination of the overstocking of pastures. Overstocking is given when due to pasturing a deterioration of the plant cover as to density and composition occurs while soil erosion is expanded. In case of an extensive pasturing, i.e. when systematic measures for maintaining an efficient vegetation cover of a high fodder value are missing, the pasturing animals are a link of an ecosystem which in its internal relations is subject to the laws of natural ecosystems. The grazing animals act on the plants within the scope of this system by their hooves, by the intensity of grazing and the selection of fodder plants. Up to a certain rate of stocking per unit of area, the ecosystem will not be disturbed, i.e. the plant cover will be reproduced quantitatively and qualitatively, the soil erosion will not be more intensive than on areas which are not pastured. When the rate of stocking will be increased further, a number of consequences will occur which, in the extreme case, may lead to the almost complete destruction of the vegetation and soil cover.

Usually, the action starts with the selective grazing of the animals biting off only those fodder plants which they like best. Consequently, these plants cannot develop seeds and sub-ground organs of storing substances. They die and disappear from the plant society. If the excessive rate of stocking is not removed, gradually more and more fodder plants will be excluded until only such species will survive which are resistant to selective grazing and being trampled upon and which are not taken by the grazing animals. Usually, these plants have a verly low fodder value. Under certain circumstances they may be taken by another less fastidious species of animal. In this way, a succession of plant societies will be brought about where one society is replaced by the following and which are characterised by a continuous decrease of the fodder value of the plant stand. Cattle pastures gradually turn into sheep and goat pastures. Such successions have been described repeatedly in literature (e.g. Horn, 1965; Weberling, 1965).

With the disappearance of the valuable and primarily eaten fodder plants, the animals start looking for fodder and cover large distances every day. Consequently, the action of the hooves on the plant and soil becomes more intensive. This applies especially to dry spells when the plant has not sufficient regenerative power and the dry soil surface is ground into dust by the action of hooves. Under this layer of dust, the soil usually is heavily compacted. The soil more and more becomes susceptibel to erosion. While the layer of dust is subjected to continuous erosion by wind, water erosion will begin with the first heavy rainfall because the surface drainage largely increases due to the scarce cover of the soil by plants and the consolidation by hooves. In this way, one gear meshes with another in case of continuous overstocking until vegetation and soil are completely destroyed as in wide regions of the Near East, North Africa and Central Asia.

The complete abolishment of these phenomena of soil destruction caused by overstocking (related to the number of animals per unit of area) or overgrazing (related to the condition of the plant cover) is impossible within the framework of extensive pasturing. There are several reasons:

1. It is not possible to secure a sufficiently uniform utilisation of the partial areas of the whole pasture land.

2. The unequal amounts of fodder available due to changing atmospheric conditions over several years cannot be balanced.

3. The adaptation of the number of grazing animals in time to the fodder available on the pastures by slaughtering animals cannot be realised because of social traditions of many pastoral tribes.

The regions of extensive pasture farming have an arid or alternating humid-arid climate. The growth of fodder is dependent on the precipitations and their distribution. In periods with sufficient rainfalls and a good growth of fodder, plant and soil will hardly be damaged. When the drought begins, however, many plants stop growing, the fodder offered is scanty and the animals bite off the plants more and more intesively producing a gnawing effect. The worsening nutritional condition of the animals and the continuously growing physical stress exerted at the same time (heat, drought, passing over large distances in search for feed and to the watering places) lead to the death of many animals. In this way, the herds are reduced every year. Before these effects on the livestock become manifest, the damages to plant cover and soil have already been caused.

The differences in the fodder offered caused by the succession of rainy and dry spells are compensated by many pastoral tribes by changing every year between grazing areas of different conditions of growth which are far away from each other. This limits overgrazing and its consequences to a certain extent. The different amounts of fodder available in consecutive years due to changing precipitations cannot be compensated unless by slaughtering animals. For the arid regions, a great variation of the real annual precipitations about the long-term statistical mean is characteristic. Moist years mean more fodder an lower losses of animals. When an arid year with a low offer of fodder follows the moist year without reducing the livestocks, then overgrazing and destruction of the soil are inevitable. Facts have shown that pastoral tribes and herders seldom are prepared to reduce their herds by slaughtering.

An essential element of extensive animal husbandry is the rhythmic migration of herds to the watering places. This necessitates the distribution of the herds and the more intensive grazing in places in the vicinity of the watering places as compared to more remote areas. The degradation of pastures and destruction of soils primarily starts in the vicinity of watering places because of the concentration of animals. An increase in the number of watering places will not solve the problem. Frequently, the livestocks are increased and the pastures even more excessively grazed because of the improved supply of water.

These correlations show that a degradation of the soil can hardly be avoided in regions with extensive pasture farming. As a rule, extensive pasture farming leads to a more or less intensive soil erosion. Therefore, advantage should be taken of all possibilities to keep soil losses within certain limits. This is possible by the following measures:

1. Adaptation of the livestock to the fodder offered by the pastures.

2. Providing a (state) fodder reserve which is used in periods of fodder shortage in order to reduce the pressure of the herds on the pastures by additional feeds.

3. Preparing and implementing pasturing plans which specify rest periods for any sub-area of the entire pasture land during which no grazing takes place so that the vegetation can recover.

4. Facilitating a more uniform distribution of the animals over the pasture land by increasing the number of watering places.

5. Purposive measures for the control of erosion (biological and technical structure formation) in particularly endagered places such as watering places, cattle tracks, milking places. Reduction of water drainage and better water utilisation by furrows parallel to contour lines along slopes which are not too steep. Sowing fodder plants on heavily damaged areas.

The most effective measure for avoiding damage due to soil degradation is the fencing-in of pasture grounds and the introduction of rotation pasturing. With this, however, extensive use is abandoned and a course taken which in connection with fodder plant sowing and fertilising leads to a more intensive forms of use where by far better possibilities of avoiding soil degradation are given.

(3) Accelerated soil erosion in arable farming

When the natural vegetation is removed and replaced by the cultivation of one or more useful plants, the farming system applied is called arable farming or crop farming. A more or less intensive working of the soil by mechanical means for the purpose of regulating the structure and weed control is characteristic. Due to the total removal of the natural vegetation and the direct action on the soil by tilling, the most radical disturbance of the equilibrium between soil forming and soil destroying forces takes place when proceeding to arable farming. The newly obtained equilibrium need not correspond to a more intensive action of the destroying forces in any case although this actually occurs in the majority of cases. The kind of displacement of equilibrium is fully dependent upon the natural conditions and the character of the farming system used. In all places where the potential danger of erosion due to the given soil and climate is rather high, tht is to say, when the unfolding of the processes of erosion is only checked by a dense natural vegetation cover, as for example in wide regions of the Tropics, an intensive accelerated soil erosion is associated with the transition to arable farming, especially when extensive and little developed farming systems (dry farming, shifting cultivation and partly monoculture) are used.

In humid warm and temperate climates with an intensive soil formation and a more or less continuous vegetation cover, the status quo can be maintained in many cases when proceeding to arable farming by intensive cropping systems, i.e. an accelerated soil erosion can be avoided. Frequently, however, the implementation of special anti-erosion measures is even necessary in intensive arable farming. It should be noted, however, that the choice of the correct soil-conserving farming method is the most economical and technically effective measure of erosion control on arable land.

Arable farming is carried out in two forms in the Tropics: shifting cultivation and permanent arable farming. As to the problems of soil erosion, these two forms of land-use are distinguished from each other.

Shifting cultivation

The interposition of a natural fallow of several years after a short use for arable farming is characteristic of the shifting cultivation. The natural fallow (forest, shrubs, grass) serves for the regeneration of the fertility reduced due to soil degradation during farming by an accumulation of organic substance and mineral plant nutrients. The accelerated soil erosion is a phenomenon of the phase of land use but it may also affect the period of natural fallow when the extent of the reduction of fertility during land use does not permit a quick development of vegetation during the fallow period after leaving the arable land. In particular, the extent of the accelerated soil erosion is dependent upon the following factors:

1. Degree of leaching and weathering of the used land

2. Size and topographic situation of the cleared plots

3. Volume and degree of dryness of the plant material to be burnt after clearing

4. Type of tillage after clearing (hoeing or ploughing)

5. Speed of development and density of the vegetation cover consisting of cultivated plants

6. Species of the cultivated plants grown

7. Duration of the land-use period and of the fallow

8. Type of the plant society of the fallow period.

Permanent arable farming

In all forms of soil change, man immediately uses the forces of nature restoring fertility by excluding the soil from utilisation for a certain time. With this, he provides the possibility of restoring the equilibrium disturbed during the period of land-use between soil forming and soil destroying forces in favour of the former.

With the transition to permanent arable farming, the period of a natural restoration of the soil to its fertility is omitted. This means that the processes of changing the fertility of the soil exclusively depend on the methods used by man in agriculture. This shows the particular importance of the use of correct agricultural methods within the scope of permanent arable farming to the conservation of the soil. An expedient farming method with respect to the conservation of the soil is considered such a method which combines the economic requirements of society in the production of vegetable products with the requirements of the natural conditions in such a way that no reduction of the soil fertility occurs in the long run. From the viewpoint of soil conservation, first and foremost the summary final effect of all partial measures of the overall system is important to an evaluation.

The following elements of the farming system exert an influence on the extent of the accelerated soil erosion:

1. Soil working or tillage

2. Species of the cultivated plants grown

3. System of the cultivation of useful plants
4. Fertilisation
5. Irrigation

Below, they are dealt with in greater detail.

Tillage

An essential aim of the cultivation of the soil is the change of the structure of the upper soil layer in accordance with the requirements of the cultivated plants. The tillage operation influences the proportion of aggregate and aggregate size as well as the density of the soil. In addition, it influences the surface condition (degree and directional orientation of roughness). Any of these properties is in direct correlation with soil erosion by wind and water:

- The size of the aggregates determines their capability of being transported.
- Proportion and size of the aggregates determine the macropore system of the soil and thus the water storage capability and the rate of drainage.
- Proportion and size of the aggregates, besides the texture, exert an influence on the water storage and moisture condition of the soil on which the susceptibility to erosion by wind depends.
- The pore system determines the soil aeration and, thus, the speed of mineralisation of organic substance by which the resistance to erosion of the soil is reduced.
- The surface roughness determines the reduction of the velocity of the wind close by the soil sorface and of the surface drainage, i.e. the kinetic enegry of the media inducing erosion.
- The pore system influences the stabilisation of the soil by the extent of rooting etc.

For these reasons, in regions with a high danger of erosion, any measure of tilling the soil must comply with the requirements of conservation of the soil. This especially applies to the whole range of the Tropics and Subtropics. Neal (1963) in this connection arrives at the conclusion that the expedient cultivation of the soil is one of the most important anti-erosion measures at all.

The requirements for tillage are distinguished somewhat depending on whether the soil is primarily endangered by erosion by wind or erosion by water.

Wind erosion prevails in the arid regions and it plays an important part in the alternating humid-arid regions. In the interest of a control of erosion, tillage must pursue three aims:

1. Providing a rough, coarse-clodded surface
2. Avoiding the development of small aggregates and a structure-less dust fraction which are highly susceptible to erosion
3. Maximum storage of moisture in the soil

In order to restrict erosion by water, which prevails in the always humid and alternating arid-humid regions, tillage must be oriented towards the following effects:

1. Reduction of the speed of the surface drainage
2. Increase of the infiltration capacity of the soil and of the infiltration speed of the precipitations with a view to reducing the rate of drainage
3. Creation of water-resistant soil aggregates which, due to their size, are not exposed to the danger of erosion.

Altogether, the principle holds that the soil should be worked so intensively only as is absolutely required by the cultivation of the plant involved. Any excessively intensive tillage operation and aeration reduces the resistance to erosion of the soil (comminution of aggregates, humus disintegration).

Species of the cultivated plants grown

The representations given in the Section on the protective function of the plants not only apply to the natural conditions but also to the "artificial" vegetation established within the framework of the arable farming. The degree of the protective function is determined by the following factors:

1. Density of the plant cover expressed in terms of the percentual extent of covering (determines screening of the soil surface against striking drops and wind).
2. Phytomass above ground (important to energy absorption, interception and formation of litter).
3. Mass and distribution of roots (influences mechanical soil stabilisation).
4. Seasonal change in the condition of the vegetation cover (reduction of the protective function during the drought).

These factors also form the basis for a judgement of the cultivated plants with respect to the soil erosion. A cultivated plant saves the soil the more, the better and more permanent it covers the soil, the wider and more finely distributed its root system is, and the larger the amount of fresh organic matter that it feeds to the soil for the formation of humus. Plants with a long period of germination, slow juvenile development, small leaf surface and branching and a small and little differentiated root system exposes the soil to the eroding forces and favours erosion. On the other hand, the soil is protected by cultivated plants when they excel in a quick juvenile growth, large volume of leaves and a long duration of development or use. A finely branched, voluminous root system such as that of the lucerne stabilises the soil mechanically.

The soil-conserving or soil-destroying action of a cultivated plant depends not only on the plant but also on the methods used for its cultivation. In general, one may say that such crops which call for large spacings and intensive mechanical tilling (maize, cotton) are conducive to soil erosion. Crops which are grown in dense and closely spaced rows or which can be broad-cast protect the soil better than the so-called row-crops. If for one crop different cultivation methods can be used, then this crop may be of different value for the conservation of the soil, depending on the cultivation method involved. For example, Hevea brasiliensis is frequently cultivated with a completely weed-free and open soil in plantations in South-east Asia. Under these conditions, severe soil erosion is not in-frequent. When the young trees are planted on areas, however, which are protected by the simultaneous growing of soil-covering plants, primarily leguminosae, then the soil erosion is practi-cally unimportant.

Any species of cereals can be drilled on sloping ground parallel to the contour lines or hillside up and hillside down. In the former case, erosion by water is impeded to such an extent that it scarcely can be prooven. When sowing hillside up and down, erosion is largely favoured.

Maize can be cultivated with idfferent numbers of plants per unit of area. It is considered as favourable to erosion because of the large spacings between rows and the slow juvenile deve-lopment, however, the greater the number of plants and thus the plant density per unit of area, the smaller is the erosion.

One can evaluate the agricultural useful plants with respect to their role in the development of processes of erosion, taking into consideration their morphology, the rhythm of development and the cultivation technology. In the handbook for soil conservation of the U.S.A. Agricultural Department, a distinction is made between three groups (USDA, 1954):

soil-depleting crops
soil-conserving crops
soil-building crops

In general, it should be emphasised that the erosion-promoting effect of a crop naturally plays a role only when the natural conditions (climate, soil, relief) effect a latent danger of erosion. The agricultural crop is erosion-promoting only to such an extent as this latent danger is caused by the crop to become effective. In general, grains can be considered to be erosion-promoting crops.

System of the cultivation of useful plants

Useful plants can be cultivated in different systems in agriculture. These cultivation systems are of importance to soil erosion inasmuch as they determine the spatial and temporal covering of the soil by plants. From the angle of soil conservation, those systems are ideal which ensure a spatially high and temporally continuous soil covering. Mixed cropping must be considered favourable without any restriction in this respect especially when staggered harvesting dates can be realised. The cultivation of tree crops in combination with soil covering crops has also proved successful.

The different role of useful plants with respect to the development of processes of soil erosion is the basis of an evaluation of any monoculture from the angle of soil conservation. Monoculture of erosion-promoting crops can lead to a total loss of the soil and that the quicker, the more aggressive the erosive forces at at the site in question and the more susceptible to erosion the soil is. The devastating consequences of maize cultivation in Mexico over decades or the wheat growing in the American Middle West are evidences of this fact. Monoculture of erosion-inhibiting plants such as sugar cane, water rice, perennial leguminosae and many tree crops need not lead to serious damages due to soil erosion not even in regions with a high potential danger or erosion. Many authors emphasise that monocultures lead to an increased erosion of the soil as compared to crop rotations but such a generalisation is not correct. Everything depends on the potential danger of erosion, the properties of the grown useful plant, and the cultivation method involved. Other points of view as such of soil conservation in connection with monoculture will not be discussed here.

The alternative of monoculture is crop rotation, i.e. the practice of growing different crops in succession on the same land. Crop rotation is of extraordinary importance to soil conservation because it enables not only an almost uninterrupted protection of the soil by a plant cover but also the cultivation of erosion-promoting crops.

It should be noted that it is of particular importance to a crop rotation to ensure that it does not produce a soil destroying effect on the whole. This overall effect can also be achieved when erosion-promoting crops are grown, provided that the crop rotation comprises so many erosion-inhibiting and fertility-promoting links which are required for compensating the negative effect. If, for example, maize is grown after maize, the soil becomes more and more susceptible to erosion due to a continuous loosening of the soil and the large losses of humus, and the part of soil removed increases from year to year. If, however, maize is grown after a perennial leguminous plant or grasses, then the organic substance accumulated under the influence of these crops will suffice to prevent considerable damage to erosion. When maize is continued to be grown, then erosion will here occur in the second and third year. If, however, after growing maize for one year again an erosion-inhibiting crop is grown, then the damage due to erosion will remain small as compared with monoculture irrespective of the above mentioned negative side of maize growing.

This shows that the task is to develop crop rotations which, on the whole, are erosion-resistant by an optimum combination of erosion-inhibiting crops.

For the humid temperate regions, the specification of such crop rotations does not offer any difficulty. Problems arise, however, in the development of crop rotations in arable farming of the arid and humid Tropics.

Within the range of the humid Tropics, the difficulty consists in the following items:

1. The majority of crops which belong to the basic foods are pronouncedly erosion-favouring. If their share in a crop rotation would be fixed according to the demand, then an erosion-resistant crop rotation would never be obtained. This especially applies to Africa but to a lesser degree to the rice-growing countries.

2. Animal husbandry is poorly developed, locally not at all, in the humid Tropics due to the presence of epidemic diseases. Added to this is the fact that arable farming and animal husbandry are separated. Consequently, possibilities of using fodder plants are missing. But just these plants come into question for compensation in order to obtain a crop rotation which does not promote erosion. When growing grasses

and herbaceous leguminosae, an economically unprofitable grass or green fallow is brought about in this way which exclusively serves for erosion control and nutrient accumulation. This green fallow, in addition, shows the tendency to turn into a wild wood fallow due to the given climatic conditions.

In the arid Tropics, the basic problem of any land-use and of developing useful crop rotations is the shortage of water mostly given. In irrigated agriculture, the arrangement of crop rotations is not associated with any difficulties. From the angle of soil conservation, in this case crop rotations are not required, for example, in the cultivation of water rice and sugar cane. In rainfed agriculture in arid regions, above all the water reserves of the soil govern the decision about the crops to be grown. The natural site conditions restrict the number of crops capable of being grown under these conditions to a few species. Such zones are present in all continents, for example that of permanent grain growing. Problems of the control of reosion by wind become very pressing in regions where dry farming is widely distributed. Dry farming is defined as the accumulation of water required by the development of a crop, usually grain, by an interposition of a prolonged fallow period (black or stubble fallow) between two crops. This fallow time is associated with a great danger of erosion which cannot be completely suppressed even when leaving long stubbles on the ground. The most successful method for restricting erosion in these arid regions is the introduction of irrigation.

Fertilisation and irrigation

The introduction of mineral fertilisation and organic manuring can considerably impede soil erosion. While mineral fertilisation inhibits soil erosion especially by promoting the growth of plants and the effects of it, organic manuring additionally activates soil-biological processes and the building of humus substances. Grove (1928) attributes the gross differences observed by him between the intensity of erosion within the range of a village and in the outside farmland in South-east Nigeria to such effects of the concentrated application of organic household wastes in the vicinity of residential settlements. Since the humus substances have a structure-stabilising effect, even with full fallow a continuously decreasing amount of soil erosion can be observed when increasing amounts of manure are applied. This not only applies to farmyard manure but also to any green manuring.

In arid regions or in humid regions with a distinct drought, irrigation enables the more or less interrupted protection of the soil by a vegetation cover. The increase of the soil moisture reduces the risk of erosion by wind because due to the increase in weight of the particles in a moist state and the increase of the bonding forces in the soil reduce the erodibility of the latter. The more exuberant development of vegetation and, above all, the more intensive growth of the roots of plants lead to increased feeds of fresh organic material as the parent material for the formation of humus. The overground plant mass of irrigated crops shades the soil better and protects it from the actions of wind and rainfall. Due to these facts, irrigation is considered as the most important means for the control of erosion.

The soil displacement can also be favoured by irrigation. Very frequently, soil material from the cana bed is transported to the fields with the water from the feed canals. In places where the irrigation water following gravity flows superficially or in furrows over the field, soil can be moved from higher parts of the field to the lower ones. In this connection it also holds that the displacement of soil is the more distinct, the quicker and the farther away it flows and the more susceptible to erosion the soil is. In sprinkler irrigation - provided correct standards and sprinkling intensity - surface drainage will not take place normally. However, spray erosion may occur especially in case of long-distance sprinklers with big drops, and sheet erosion in association with too high sprinkling intensities. When irrigation is correctly applied, however, considerably damage by erosion have not to be expected.

(4) Accelerated soil erosion and forestry

As compared with other plant formations, forest formations offer the soil the most effective protection against erosion. In many cases, forests form the natural vegetation cover in regions with an extremely high potential danger of erosion, namely, on slopes and in case of heavy rainfalls. The important function performed by the forest in the wtaer regime of a geographic region is not subject of our representations here. The balancing effect of forest stands on the supply of water in a hydrologic catchment area is in direct correlation with the protection against erosion, however.

Lumbering can lead in two ways to soil erosion:

1. by an excessive thinning of the density of the stand and unfavourable influence on the composition of species in case of extensive use
2. by the direct effects of lumbering (cutting, transport)

Forests may be quite versatile by their composition of species and age classes. Depending on their condition, they have to be evaluted differently with respect to their soil-conserving properties. From the angle of soil conservation such forests are most valuable which are of a multifarious composition, for example, deep rooting and shallow rooting wood species should be combined where the herbaceous flora and the shrubs

...

are adequately developed and all age classes are uniformly represented. Forests consisting of one or only a few species are susceptible to disasters (pests, windfall, fire). Together with the complete or partial destruction of large areas of such forests, frequently erosion by water is initiated to a high degree. This especially applies to areas where the wood has been destroyed by fire and, together with the living plants, the litter consisting of organic material and sometimes even a part of the soil humus are lost by mineralisation.

By an exclusive use of certain kinds of wood and by an inexpedient reforestation, the capability of the forests to protect the soil permanently and effectively from erosion has been considerably impaired in many countries of the world. Such phenomena are characteristic first and foremost of the woods and forests in the temperate latitudes. The tropical rain forest of South America, Africa and Asia is so heterogeneous in his composition of species and age classes that it excels in an extraordinary stability. It reliably protects the soil from erosion by water.

Damage due to erosion after the destruction of forests by fire are relatively frequently found in the tropical arid regions in the range of the deciduous and, still more so, of the distinctly dry woods. This naturally applies to naturally caused fires and fires caused by man (fire clearing).

Whereas the promotion of processes of erosion by changing the composition of forests will become visible in the course of time and the correlations will not be readily realised in many cases, faults in lumbering frequently lead quickly and directly to erosion damage, especially on slopes. Clear felling always leads to erosion by water, irrespective of the natural conditions. This is due to the fact that in such regions where forest formations form the natural vegetation, ample rainfall will occur throughout the year or during prolonged periods of time at least which then effect erosion. From the angle of soil conservation, other systems of lumbering as clear felling must be employed.

Since the kinds of timber of the forests of the tropical and subtropical climate in many cases do not form stands, clear felling frequently used in the forests of the temeprate climate is not taken into consideration. In view of the rapid growth of the tropical rain forest, gaps due to felling individual trees will be filled so quickly that there is no danger of erosion. This even applies to slopes. In places where tropical timbers form whole stands (teak, Shorea robusta, Mora excelsa), the felling of single trees is preferably used. Clear felling for the clearing of land for arable farming cannot be included in the management of growing timber. When growing tropical timber in plantations other yardsticks of forest management must be used. Frequently, the initiation of special measures of protection against erosion are required.

The forest formations of semi-arid regions are much more endagered than the forests of humid climates. The fact that the arid climate is adverse to the growing of timer considerably impairs the regeneration of forest and shrub societies after their destruction. Frequently, it is practically impossible. The shortage of timber and the widely distributed pasture farming in these regions are a continuous source of dnager to the forests of semi-arid regions. In many countries, they have been destroyed to a large extent so that, today, great financial and technical efforts have to be made in order to reforst the devastated lands.

Various scientists are in agreement of the fact that the problem of soil conservation in connection with the management of growing timber is, above all, an educational and propagandistic problem. It must be made clear that the yield of timber is only one aspect of the usefulness of forests and that the effects exerted by forests on climate, water regime, and soil erosion are a second aspect which by no means is less important, especially in semi-arid regions.

The protection of forests from grazing animals is of particular importance. The use as a pasture, a widely used form of secondary utilisation especially of wooded steep hillsides, is extremely detrimental espeically in periodically dry regions because this may lead to the complete destruction of the forest because of suppression of the growing of young plants if intensive grazing and vigorously biting off takes place. Therefore, again and again the requirement is raised to protect woods and forests from grazing animals.

(5) <u>Control of erosion by water and wind</u>

<u>Principles</u>

The control of the accelerated soil erosion is not a question of technical methods. Such measures of soil erosion control are well known, tested for their efficiency in practice and sufficiently versatile in order to provide solutions suitable for all conditions involved. The central problem consists in the fact that the most effective and at the same time less expensive variants of control of erosion can only be developed from an appropriate overall system of regional land-use. These are systems of land-use which in the sense of the world soil charter and the world soil policy aimed at (UNEP, 1982) permit an effective and stable utilisation of the biogeocenosis of the earth and, within this scope, of the natural resources of soil and water.

Viewed from the angle of control of erosion, three principles are of particular importance:

1. Prophylaxis
2. Regionality
3. Complexity

The principle of prophylaxis results as a logic consequence from the fact that the reduction of the soil fertility and the losses of arable land caused by accelerated soil erosion, measured against socially relevant spaces of time, are irreversible. Moreover, prophylactic control of erosion is more inexpensive and can be carried out easier. The control of the developed forms of wind erosion (quicksand, shifting sand dunes) and water erosion (ditch and gully erosion) is difficult, expensive and frequently can only be carried out with the help of considerable technical means.

The difficulty of the prophylactic control of erosion consists in the fact that readiness for its implementation is depending on the understanding of the necessity of anti-erosion measures. This applies to the direct land user (farmer, tenant) or owner of land and the competent state authorities and institutions. The history of the last few decades has shown that erosion had to take desastrous extents may times before the readiness for the expenditure of financial and technical means for the conservation of the soil was brought about. All experiences confirm uniformly that prophylaxis must be one of the basic principles of soil conservation. The realisation of this principle calls for a careful assessment of the potential danger of erosion in the various regions of land-use by agriculture and forestry in order that the measures adequate to the given conditions can be determined and initiated.

The principle of regionality arises from the fact that both natural and social conditions of soil destruction by erosion normally occur throughout large areas. When these two conditions act together, intensive and over large areas distributed phenomena of soil erosion occur which sometimes suddenly turn into catastrophes. Important aspects of promotion of erosion within the scope of pasture farming, arable farming and forestry have already been dealt with above. The most important faults in land-use which promote erosion are:

- incomplete soil covering (especially full fallow)
- arable farming on too steep slopes
- tillage on hillsides in the direction of the inclination
- monoculture of crops promoting erosion
- wrong way of working the soil
- poor economy of humus
- overgrazing
- uncontrolled burning of pastures
- complete deforestation or clear felling of forests.

The principle of complexity results from the correlation of social and natural factors in the occurrence of accelerated soil erosion. The control of soil erosion in endangered regions is only possible by a comprehensive system of measures throughout this region. This system must comprise a great number of individual measures of which only the most important ones will be given below:

1. Information of farmers and land owners about the consequences of soil erosion and the possibilities of preventing it
2. Classification of regions into utilisation classes
3. Providing legal regulations about soil use and soil protection
4. Financial and moral encouragement of soil users who carry out soil protection measures
5. Promotion of the cultivation of soil-protecting crops and tillage operations that care for the soil
6. Making available the required technical means
7. Carrying out the most expensive measures for restoring the entire region to normal conditions by the state
8. Removal of the centres of erosion by appropriate measures

Beyond these principles, of particular importance to the control of erosion is the fact that the same land-use systems and individual measure, in dependence on the natural environment, produce an erosion-promoting effect to different extents. The "potential danger of erosion" is decisive because only when a potential danger of erosion is present, an intensive accelerated soil erosion is caused by faults in land-use.
The potential danger of erosion results from the theoretically available maximum energy for erosion processes. The potential danger of erosion is the erosion which occurs when the natural vegetation is completely removed and corresponds with the possible maximum action of energy on the soil due to precipitation, surface drainage and wind.
In contrast to this, the acute danger of erosion is the probable or possible erosion in a given system of land-use.

One of the essential bases for the control of soil erosion therefore is the regional analysis of the potential danger of erosion.

Methods of the direct control of erosion

All methods of the direct control of erosion realise one or several of the possibilities of taking influence on the erosion process which result from the mechanism of erosion by water and wind, from the equilibrium between soil-destroying and soil-building forces and from the protective function of the vegetation. In this sense, the prophylactic and restoring measures of erosion control pursue three basic aims:

1. The reduction of the kinetic energy and, thus, the erosive force of wind and rainfall before their direct contact with the soil as the object of erosion. The reduction of the kinetic energy of the air current is caused by obstacles of dead (masonry, fences, dead plant parts) or living material (hedges and plant growths) or by raising the wind from the soil surface by means of a buffer layer (vegetation

cover, mulch). The reduction of the energy released by the bouncing drops before the rainwater contacts the soil is achieved by soil covering by means of rigid or elastic, living or dead material.

2. The reduction of the surface drainage and its kinetic energy. For this purpose, all measures are suitable which increase the pore-volume of the soil and the stability of the structural aggregates of the latter. In addition, energy and amount of the water flowing off can be reduced by roughening the ground surface (tillage,growing of perennial herbaceous plants and grasses), regulating the relief by measures diminishing the slope (terraces), and interrupting the slope (contour line furrows and ditches).

3. Increasing the stability to erosion of the soil. This aim will be reached by structure amelioration (deep loosening, removal of zones of compaction and petrification), organic manuring, growing of crops adding to the humus formation, soil-saving tilling methods and the like.

In the course of millenia of land-use by man, many simple and complex, inexpensive and more expensive methods of erosion control have been developed. These methods have been locally modified and, under the influence of natural and historical circumstances, sometimes are spread only within certain geographic regions.

A classification of the great number of different methods for soil conservation, as it is required for evaluation and description, can be established according to several points of view. For example, one could group the methods into the two comprehensive divisions methods for the control of wind erosion and methods for the control of water erosion. Since, however, a greater number of methods is suitable both for the control of erosion by wind and erosion by water, this seems to be not particularly expedient. Finally, a classification of the methods according to the similarity of the principle of control of erosion at the bottom of them. Such a classification was used by Tempany (1949). The following systematisation was effected in imitation of this classification.

1. Methods of arable farming:

   Appropriate tillage, contour cultivation, wing and strip cultivation, crop rotation, mulching.

   These methods can aim at the reduction of the drainage rate and energy and at the protection of the ground surface from the bound of drops and the action of wind.

2. Control of erosion by means of special plantations:

   Windbreak plantations, strips of grass and hedges parallel to contours, soil covering crops.

   These are methods which use the living plant for protecting the soil from the direct actions of precipitations and wind and which may also serve for the retardation of the surface drainage and thus for increasing the rate of infiltration.

3. Artificial changes of the relief:

   Contour furrows, ditches and dams, discharge ditches, terraces.

   The change of the surface relief regulates the surface drainage. In contrast to the methods of arable farming for influencing the ground surface, this is a permanent change and can be applied to areas used for arable farming and for pasture farming.

4. Chemical methods:

   Artificial incrustation of the surface, chemical improvement of the structure.

   These methods serve for an increase in the resistance to erosion of the soil and, when the structure is improved, also for a reduction of the rate of drainage.

5. Technical and biological structure formation:
   Gully formation, dune compaction.
   These methods serve for the control of advanced forms of erosion.

The importance of the methods of arable farming

The methods of arable farming for the control of erosion occupy a special position in comparison with the other groups. They do not represent methods which are independent of arable farming to a certain degree or additional to it such as the arrangement of windbreak strips and of terraces or the application of chemical for improving the structure of the soil but they coin the mode of land-use as an immanent constituent of it. They have to be considered as a preparation or framework within which the farmer – depending on the danger of erosion within the range of the soils used by him – has to arrange his system of land-use. This shows that the use of these methods is largely depending on the understanding of the necessity of utilising these possibilities of a prophylactic control of erosion and on the economic pre-conditions. The use of an appropriate farming system in many cases already offers such an effective protection against erosion to the soil that one can dispense with additional measures which frequently involve considerable additional costs. Mulch planting used in the U.S.A., when carried out parallel to the contours on slightly sloping hillsides, can render superfluous the arrangement of terraces because the furrows running parallel to the contours of the slope in connection with the remainders of mulch sufficiently increase the infiltration of the rainwater. Cultivation in wings for breaking the wind within a suitable crop rotation, in flat land where the soils are endangered by wind, may already provide such a radical effect that the planting of stripe of wood can be omitted. On the other hand, strips of trees do not offer a similarly safe protection from erosion when arable farming is carried out between them in a form that promotes erosion.

Although frequently one cannot dispense with a combination of arable farming methods in order that the danger of erosion is safely controlled, any complex control of erosion should first and foremost rely on these methods, nevertheless, because they promise the better effect with relatively low costs.

III. 2.1.6.4. Secondary soil acidification

(1) Definition

Acidification is a natural process to which all soils are subjected in which continuously or periodically seepage water formation and profile washing-through take place. Consequently, it is associated with the alternating humid-arid and humid climates. The time taken by this process is quite different, depending on the reserves of basic cations (Ca, Mg, Na, K) contained in the geologic parent substrate of the soil and the intensity of the washing through the profile. In any case, it requires spaces of time relevant to the natural development of the soil, i.e. centuries and millenia. Anthropogenic influences of different kinds may accelerate the acidification of the soils under certain circumstances. Depending on the intensity of the effect of the acidifying influences and the properties of the soil, the pH may be lowered rapidly. In a few years, a decrease of the soil pH by more than one unity is possible. The anthropogenically conditioned process may be termed as "secondary acidification". The secondary acidification of the soils must be considered process of soil degradation because acid and very acid soils have a restricted fertility due to the high acidity. The majority of plants normally are capable of growing within a wide range of pH as tests in a solution culture have shown again and again. The negative influence of soil acidification on many plants, therefore, must be attributed mainly to indirect effects. Above all, three factors come into question:

1. Base impoverishing
   The acidification of the soil measurable in terms of decreasing pH values is an expression of the progressive base acidification of the soil due to leaching. In case of very low pH value (3.5 to 5.0), the shortage of basic cations can lead to malnutrition.

2. Occurrence of toxic substances
   In an acid and very acid environment (pH 5.5) free Al^{3+} and Mn^{2+} ions may occur in concentrations which produce a toxic effect on the plant. The free Al^{3+} ions are aluminium which has been displaced from the lattice of the silicates, especially from the octahedron layers of the layer-silicates, by hydrogen ions. In the event of a sufficient hydrogen-ion concentration, no Al-hydroxides but Al^{3+} ions are produced which are bonded to the exchange complex relatively firmly but in an exchangeable form. In case of a pH equal to 4, already >10 % of the cation-exchange capacity saturated with Al^{3+}. With increasing Al^{3+} saturation of the exchange complex, the concentration of the Al^{3+} ions also increases in the external solution although considerable Al-concentrations only take place with an Al-saturation of 60 % (Kamprath, 1972). When 0.1 ppm are exceeded, injuries to plants increase. Essentially they are due to the fact that Al^{3+} ions are taken in by the roots and stored. The aluminium precipitates phosphate ions and prevents them from being transported further. Disturbances in the phosphate metabolism will occur due to impeded P-intake and impairment of the sugar-phosphorylation in the interior of the cells (Scheffer and Schachtschabel, 1976).

3. Reduction of the biological activity
   The microbiological transformations in the soil and the structure of the microbe population are reaction-dependent.

In the neutral and slightly acid range, in general optimum conditions are given for the microbiological total activity. In the acid and very acid environment, the conditions become more unfavourable. A practically exclusive development of acidophilic genera and species, a receding into the background of bacteria as compared to fungi, and an altogether reducing microbiological transformation of matter take place. Since there is a direct and positive correlation between biologic activity and fertility, the conditions for the growth of higher plants become more unfavourable in case of acidification. In this connection, changes in the circulation of the nutrients, release of growth substances and inhibiting substances, the CO_2 concentration in the soil air, and the decrease of the biological structure formation over a prolonged period of time play a part.

(2) <u>Factors of secondary acidification</u>

A number of different factors contribute to the secondary acidification of the soil. These are

1. SO_2 concentration in the atmosphere and in the rainwater due to the combustion of fossile energy carriers and the emanation of sulphurous gases by industrial plants.

2. CO_2 concentration in the atmosphere and in the rainwater due to the increasing combustion of fossile energy carriers.

3. Increasing mineral fertilisation.

4. Increasing demand for agricultural products by which considerable amounts of basic cations are drawn from the biological circulation of nutrients in certain sites.

5. Measures of land reclamation by measures of amelioration which lead to the so-called "sulphide-acidity".

Below, these factors will be explained.

Increasing SO_2 concentration in the atmosphere and rainwater

Gaseous sulphur compounds get into the atmosphere also within the scope of natural processes, e.g. volcano eruptions, ocean spray, biological sulphur transformations, forest and steppe fires. These processes are constituents of the natural sulphur circulation. The industrial development and the increase of the combustion of fossile energy carriers (pit coal, brown coal, mineral oil) have led to the fact that the supply of sulphurous gases into the atmosphere due to human activities today is 3.5 times that of the natural release (Möller, 1981). For 1970, a ratio of 3 : 1 was calculated, in absolute value this is equal to 70 million tons of S from anthropogenic sources and 23 million tons of S from natural sources. This illustrates the rapid increase of the sulphur load on the atmosphere. For the year of 2000, an anthropogenic SO_2 emanation of 200 million tons is forecast. 94 per cent of the anthropogenic SO_2 load on the atmosphere are due to the combustion of fossile fuels, the rest is due to the extraction of metals from sulphidic ores and the production of sulphuric acid. When burning coal and petroleum, the sulphur contained in these fuels, minerally and organically bonded, is oxidised into SO_2. About 2 to 3 per cent of the sulphur are immediately oxidised into SO_3 which is dissolved into sulphuric acid in the atmospheric water. SO_2 is also dissolved in the atmospheric water and, under these conditions, is transformed into sulphate particularly quickly.

The sulphur emitted into the atmosphere gets onto the surface of the earth by dry or wet deposition. Dry deposition is defined as the adsorption and absorption of gases and aerosol particles by the surface of the earth. Wet deposition is effected by washing out (absorption of gas or aerosol particles by the falling precipitation) or raining out (absorption of gas or aerosol particles by the formation of clouds, partly in the form of condensation nuclei). From the atmosphere, they get onto the surface of the earth (Möller, 1981),

45 % by means of dry deposition of SO_2
43 % after oxidation into sulphate (in aqueous phase or bonded to ashes or smoke particles)
12 % as so-called wet deposition of SO_2

For the secondary acidification of the soil it is of decisive importance that hydrogen ions are produced during the SO_2 oxidation in the atmosphere which may reduce the pH value of the precipitation water to 4 or 5. The increased hydrogen ion concentration of the precipitations is the cause of the intensified leaching of basic cations from the soil.

The problems associated with the anthropogenic enrichment of SO_2 in the atmosphere are attributed to industrial centres and overcrowded regions. The transport of SO_2 and SO_4^{2-} in the atmosphere takes place in dependence on the atmospheric conditions over distances of up to about 1000 km from the source of emanation. This relatively small displacement aggravates the problem in industrial regions and, on the other hand, is due to the fact that huge regions of the continents are not yet subjected to this form of secondary acidification.

The question whether the sulphur emanation due to the combustion of organic masses in regions with regular burning of pastures or forests in clearing has any importance to secondary acidification remains to be open. The transition in the production of energy from the combustion of fossile organic substances to other methods will cause a drastic change of the situation at the beginning of the next millenium.

Increasing CO_2 concentration in the atmosphere and in the rainwater

In burning organic substances, carbon compounds will also be oxidised and emitted into the atmosphere. Carbon dioxide dissolves in the atmospheric water into carbonic acid and increases the hydrogen ion concentration of the precipitations. The influence of the anthropogenic CO_2 emanation on the carbon circulation is considerably smaller than that of the SO_2 emanation on the natural sulphur circulation. This is due to the fact that the main source of the CO_2 emanation is respiration of the living organisms. The ratio of the anthropogenic emanation to natural emanation is 0.08 for CO_2 (with 10.6 of CO) and in absolute figures 16 thousand million to 200 thousand million tons per year. Irrespective of this fact, the anthropogenic CO_2 emanation must basically be considered as a factor of the secondary acidification.

Withdrawal of basic cations by means of the harvested crops

In the natural circulation of substance, the acidification of the soil is retarded by the incorporation of, frequently, considerable amounts of basic cations into the biomass or - seen dynamically - into the biologic mineral matter circulation of the biogeocenosis. The basic cations contained in the organic substance are protected from leaching and, after dying and mineralisation of the substance, feed into the soil. The system of subsistence farming exerts an negligible influence on this mechanism. With increasing market production of agriculture and forestry, and with increasing yields, increasing amounts of cations are withdrawn from the production site. These cations are no longer available for the neutralisation of the hydrogen ions fed into the soil, in other words, the withdrawal of cations together with the harvested crop favours the enrichment of hydrogen ions in the soil.

Mineral fertilisation

Not in any case, mineral fertilisation produces an acidifying effect on the soil. Acidification occurs when fertilisers are employed whose cation is more readily accepted by the plant than its anion, e.g. $(NH_4)_2SO_4$ and K_2SO_4. These fertilisers are termed as "physiologically acid" because the acid residue remaining in the soil contributes to soil acidification. Although the anion will be neutralised by the basic cations present in the soil, especially by the alkaline-earth ions, but at the same time the concentration of hydrogen ions and, in the advanced state, of Al^{3+} ions on the exchange complex will be favoured.

Particularly intensive fertilisation with nitrogen in the form of ammonium fertilisers as well as fertilisers by the transformation of which ammonium ions are produced such as urea favours the secondary acidification. Since ammonium ions are not all taken up immediately by the plant, conditions for an intensive nitrification are brought about, that is to say, for the microbial transformation of ammonium into nitrate nitrogen. In this process, nitric acid is produced whose hydrogen ions reduce the pH value of the soil and favour the base reduction by leaching.

For the application of sulphuric ammonia, the acidifying effect can be represented by the following summary equation:

$$(NH_4)_2SO_4 + 4\ O_2 \longrightarrow 2\ HNO_3 + H_2SO_4 + H_2O$$

$$[\text{exchanger}]\text{-}2Ca + 2HNO_3 + H_2SO_4 \longrightarrow [\text{exchanger}]\text{-}4H + CaSO_4 + Ca(NO_3)_2$$

Sulphide-acidity

Sulphides can be contained in the soils. These sulphides originate either from the rock from which the soil developed, e.g. pyrite or marcasite, or they were brought about by sulphate reduction under reducing conditions. Sulphate ions may get into the soil by salinisation in arid regions an by sea water penetration in coastal regions. The reduction of sulphate ions is promoted by the presence of undecomposed organic substance. Particularly favourable conditions for the accumulation of sulphidic sulphur are, therefore, given in the slime of the coasts of oceans influenced by the tide, for example, in the mangrove swamps of the Tropics which extend over thousands of kilometres of coastal line. Due to different interventions by man conditions may arise under which the sulphidic sulphur is subjected to a rapid oxidation, in most cases, however, these are measures which directly serve for the regulation of the water egime, i.e. the carrying-off of excessive water through drainage systems. The improved soil aeration causes the oxidation of the sulphides into sulphuric acid:

e.g. $2\ FeS_2 + 7\frac{1}{2}\ O_2 + H_2O \ \text{---}\ Fe_2(SO_4)_3 + H_2SO_4$

$$Fe_2(SO_4)_3 + 2\ H_2O \ \text{----}\ 2\ Fe(OH)SO_4 + H_2SO_4$$

The sulphuric acid produced is neutralised into gypsum by calcium and favours the enrichment of exchangeable hydrogen and aluminium by the precipitation of exchangeable cations. This leads to a sudden considerable drop of pH to values below 2. Under these conditions, an intensive protolytic decomposition of silicates takes place which assists in the development of free aluminium.

(3) <u>Importance of the secondary acidification</u>

A quantified assessment of the importance of the secondary acidification is difficult. Möller (1981), for example, considers it an unsettled question whether the formation of hydrogen during the oxidation of SO_2 in the atmosphere leads to a global acidification. It is clearly established that the secondary acidification manifests itself most intensively in the field of overlapping of the influence of industrial centres, intensive land-use in agriculture and poorly buffered soils that are poor in base. Topically, the acidification by an emanation of SO_2 is a problem of the industrial countries of the temperate climatic region. This does not mean, however, that the developing countries of the Tropics are not faced with the problem of the secondary acidification. The transport problem in these regions is associated especially with the enormously wide distribution of soils with a low buffering capacity for the soil reaction in the humid regions. It refers especially to the ferrallitic and fersiallitic soils whose buffering capacity is low because of the high degree of leaching and weathering and to the arenosole with a sandy texture. The low buffering capacity of these soils allows the acidifying effect of measures inevitable within the framework of intensive plant production, such as intensive mineral fertilising and transport of large amounts of cations together with the harvested crop, to take action rapidly. Poulain et al. (1980) consider the rapid acidification of the soils in case of intensive agricultural land-use to be the central problem of fertility of the humid Tropics. According to Velly (1974), the fertilisation with 620 kg of N/ha on a fersiallitic soil of Madagascar has reduced the pH value from 5.2 to 4.2 in a period of only three years, and the content of exchangeable aluminium rose from 5 to 55 and that of manganese from 5 to > 80 ppm, at the same time. The yield of groundnut dropped to 40 % because of Al toxicity.

(4) Prevention and control

The secondary acidification can be removed by direct measures. The supply of basic cations leads to an exchange of the hydrogen ions absorbed by the negatively charged exchange complex of the soil. The hydrogen ions displaced into the external solution of the soil will be leached rapidly in humid regions. Basic cations are supplied together with a few fertilisers, e.g. simple superphosphate or nitrochalk. The most effective direct method of control is liming, that is to say, the feed to the soil of $CaCO_3$, $Ca(OH)_2$ or CaO in a finely ground form. Liming neutralises the hydrogen ions into water and causes a precipitation of Al^{3+} ions as polymeric aluminium hydroxides. The neutralisation effect of liming is aided by the exchange of cations which are replaced by calcium.

Liming is a widely used effective measure which naturally causes additional costs which will be the higher, the larger the distance over which the basic additives have to be transported. Since the input of lime usually amounts to one to several tons per hectare, considerable masses have to be transported and spread.

The secondary acidification can also be counteracted by a reduction of the acidifying influences. The industrial emanation of SO_2 can be restricted at least by means of special technologies until the replacement of the combustion of fossile energy carriers. The acidification due to an intensive mineral fertilisation is reduced by a well-balanced supply of anions and cations. Measures of ground-water regulation properly adjusted to the sulphide-acidity and exactly planned and carried out not infrequently permit the avoidance of extreme acidification processes.

III.2.1.6.5. Structure degradation

(1) Definition and importance

The cavity system of the soil body governs the water and air regime of the soil and also the technological behaviour of the latter when it is subjected to mechanical action. The main features of the cavity system are the total pore volume, the pore-size distribution and the pore continuity. The condition of the cavity system in the soil is determined by texture, structure and biological activity. With this, the structural condition of a soil is an essential fertility-determining feature of it. Structural condition is defined in the most general sense as the way of spatial arrangement of the solid soil constituents. This spatial arrangement of the solid soil constituents is in essence coined by the degree and mode of unification of primary particles into aggregates. The term structural condition includes the aspect of structure stability.

The changes in the course of structure-determining processes due to the land-use in agriculture and forestry as well as the direct mechanical actions by the operation of machines cause changes in the structural condition of the soil. Although the structural condition of the soil can be improved by correct land-use, the prevailing trend is a deterioration of the soil structure, a structure degradation. This is a destruction of aggregates, an increase of the share of dust in the soil, a reduction of the macro-pore volume and of the pore continuity, and an increase of the density of the soil. Consequently, the internal drainage and a soil aeration are impaired; the conditions for a proper rooting of the soil become more unfavourable, the soil increasingly tends to form stagnant water and to incrustation after precipitations. The increase of the share of dust and the increasing surface drainage lead to an increased erosion by wind and water. The fertility of the soil decreases noticeably.

It is very difficult to quantify the extent of the damage due to structure degradation. This applies both to the areas subjected to structure degradation and to the degree of the destruction of structure on the area in question and the yield losses caused in this way. The reasons for these difficulties in the recording of the structure degradation are in the field of measuring methods and in many cases the lacking of reference standards in the form of non-influenced areas with an intact structural condition. Irrespective of these problems, internationally the idea is more and more accepted that the structure degradation is one of the decisive sources of the loss of fertility of the soils. Young (1976) in this connection emphasises that the lingering character of the processes and the missing of striking soil-morphological concomitant phenomena has internationally led to an undervaluation of this phenomenon. Although this thesis cannot be supported by documentary evidence in the form of measuring results, it can be stated alone on the basis of the knowledge of the causes of structure degradation that practically all arable land and the major part of the soils under natural grassland are subjected to struture degradation. There are only differences in the degree of the destruction of soil since the load on the soil is different and with respect to structure stability there is a considerable differentiation of the soils. On soils exhibiting a severe damage to structure, especially in case of plough pan compaction of the soil and subsoil compaction, yield losses of 50 per cent and more may occur. The structure degradation thus may render ineffective the expenditures for increasing yields by intensification measures such as fertilising and irrigation, for some part at least. As compared with such fields as clay mineralogy and cation exchange, to mention but two examples, the phenomena of structure formation have by far less been in the centre of interest of studies of soil science. While in such fields as nutrient supply for the plant the pre-conditions for regulating interventions are already quite good, we can avail ourselves only of insufficient knowledge and possibilities with respect to true alternatives of the present methods of land-use which inevitably lead to soil and yield losses due to structure degradation. We have not succeeded in getting beyond some rudimentary developments which have led to methods useful for certain soils such as the plough-less tillage.

(2) Causes of structure degradation

There is quite a number of interventions by man into land-use which have a structure-changing effect. The decisive factors of structure degradation, however, clearly are

1. loss of humus
2. loading the soil by heavy machines and tillage in the event of an unfavourable water content.

As compared with these factors, influences such as increased leaching of bases, changes in the salt concentration of the soil solution, alkalisation by irrigation, etc., recede into the background.

(a) Loss of humus

The humus, which is the whole postmortal organic susbtance in the soil, influences the structural condition directly and indirectly. The direct influence is based on the role of the humic substances as cementing substances in the formation of aggregates. In this connection, the coupling of clay silicates and humic substances is of particular importance (formation of "clay-humus complexes").

The indirect effects are based especially on a promotion of the biological overall activity in a soil with high contents of mineralisable organic substances (non-humic substances, "nutritive humus"). The ample offer of utilisable energy and carbon sources provides favourable pre-conditions for high population densities and intensive vital activities both of representatives of the mesofauna and macrofauna and of the microflora in the soil. The formation of the important and usually continuous biopores having a diameter of more than 50 µm by the fauna and the so-called "biological structure formation" of aggregates by bacteria and fungi, including the mucilaginous substances emitted by them, improve the soil structure. A high biological activity favours the rooting of the soil by higher plants and thus the development of biopores in the form of root channels as well as the enrichment of the soil with organic substance. Altogether, there is a dirct correlation between the humus content of mineral soils and their structural condition: The higher the humus content, the better the structure. From this follows the reversal: humus losses effect a deterioration of the structural condition.

The inclusion of a soil in the agricultural use is normally associated with a more or less rapid reduction of the humus content. When the soil is used for arable farming, the latter is more pronounced than in the use for pasture farming. The reduction of the humus content of the soils in agricultural use is the consequence of the interaction of the elements which determine the carbon circulation in a certain site. The content of a soil of organic carbon under natural conditions depends on the following factors:

1. Supply of organic substance to the soil, i.e. net assimilation performance of the plant cover.

2. Intensity of the mineralisation processes and proportion of the substance decomposed into CO_2, H_2O and salts by these processes (non-humic substances, humic substances).

3. Intensity of the formation of humic substance and effect of humic substance stabilisers (clay silicates, trivalent iron).

4. Leaching of organic substances and humus loss by top soil removal in situations influenced by erosion.

When leaving out of account the leaching of humus that is insignificant in the majority of soils and the possibility of losses of humus by erosion, then the mechanism regulating the humus content is reduced to

1. the amount of the substance supplied
2. equilibrium between mineralisation and humification.

The greater the annually fed amount of fresh organic substance and the more the equilibrium is displaced in favour of the humification (e.g. by a high content of three-layer clay minerals), the higher the content of humus. The humus content also increases when the mineralisation is impeded due to a high water content and poor aeration of the soil.

Any reduction of the feed of fresh organic substance to the soil and any change in the soil condition that favours the processes of mineralisation lead to a reduction of the humus content. In this connection, a new state of equilibrium is aimed at and established in accordance with the changed conditions. The transition to agricultural land-use normally means a reduction of the feed of substance and also the favouring of processes of mineralisation. The replacement of the natural vegetation cover does not necessarily means a smaller net assimilation per unit of area. The reduction of the supply of organic fresh substance is effected by

1. the gathering in and removal of harvested crops and
2. the destruction of disturbing organic substances by fire frequently practised for reasons of production technology (clearing of wood by fire, pasture burning, stubble burning, burning away of sugar cane before harvesting, etc.).

Arable farming usually is based on the one or other form of soil loosening. This loosening means an improvement of the aeration of the soil and, since mineralisation processes chemically are exidation processes, effects an accelerated microbial and abiological mineralisation of the humus. The decomposition of humus initiated with the transition to arable farming will proceed the quicker, the higher the humus content of the soil in the natural condition was maintained by a high supply of substance at high rates of mineralisation. These conditions are given in regions with tropical rain forest formations. Under these conditions, a rapid loss of humus takes place after clearing, and this the more so since the soils formed under these forests have a low content of humus stabilisers and, thus, of permanent humus. If the natural humus content is due, to a higher degree, to the inhibited mineralisation (drought) and intensive humification (basic environment, high N content, high content of humus stabilisers, alternating humid-arid conditions) with a moderate supply of fresh substance, then a gradual decomposition of humus over a prolonged period of time takes place after the transition to arable farming. While, in the former case, the new anthropogenic equilibrium will be established in 2 to 5 years, in the latter case this process takes several decades. In the tropical soils with a free inner drainage, the following mean contents of humus can be reckoned with under natural vegetation conditions (Young, 1976):

tropical mountainous situations (1500 - 3000 m)	5 to 10 %
rain forest regions in lowland	3 to 5 %
moist savanna	2 to 3 %
dry savanna	1 to 2 %
arid regions	0.5 to 1 %

In soils of the Tropics subject to arable farming, the humus content will drop to 30 to 60 % of the humus content under natural vegetation. This decrease is slightly higher than in the temperate climate where humus content decreases to 50 to 70 % of the original value. The greater reduction of humus in the Tropics is due to the more intensive mineralisation because of the climatic conditions (high ambient temperatures) and the composition of the edaphon (predominance of the bacteria, extreme activity of the termites). The humification is smaller than under comparable vegetation cover of the temperate climate at least in the soils of the humid regions with a high degree of leaching and weathering.

Although, in general, it is possible not only on smaller areas to keep the humus content at the level of the content given under the original natural vegetation cover, the loss of humus can be kept within certain limits by appropriate measures. All measures must start from two principles:

1. To supply a maximum of organic substance to the soil.
2. To avoid an unnecessary favoruing of the processes of mineralisation.

The supply of organic substance to the soil is possible by means of the following measures:

- interposition of a natural fallow
- working into the soil of available plant material which is not used in harvesting.
- cultivation of crops having a large root mass in the form of fine roots
- growing plants for green manuring
- working of farmyard manure into the soil
- preparing and working in of compost
- growing grass for a period of several years.

The separation of arable farming from animal husbandry in wide regions of the Tropics, especially in Africa, is an extraordinarily unfavourable circumstance with respect to the prevention of humus losses in arable land. Among the fodder plants, there are many humus-producing genera and species but the farmer has only limited possibilities of utilising the fodder. The lacking animals cannot provide any noticeable production of farmyard manure. From this angle, the promotion of mixed farming is imperative under all circumstances.

The avoidance of an unnecessarily intensive mineralisation of organic substances calls for the observance of two viewpoints: First, tillage for loosening and comminution should be effected only to such an extent which is absolutely required for the crop to be grown. The lower the degree of loosening and aerating the soil, the smaller the mineralisation of humus will be. Second, an unnecessary heating of the soil should be prevented. Any measure which will add to the shading of the soil will retard the mineralisation. Mulching, i.e. the application of a layer of dead organic material to the soil, has proved a success. When using plant remains, organic substance will at the same time be fed.

(b) Loading the soil by machines and compacting the soil by wrong tillage

With an increasing intensification of the plant production, the degree of mechanisation also increases. The arable land is subjected to the operation of machines at shorter intervals and which become heavier. This means an increasing compressive load on the soil which may lead to a noticeable soil compaction. The soil compaction is effected to the detriment of the macropores ($> 10\,\mu m$ mean diameter). Consequently, the internal drainage of the soil is impaired, the tendency to the formation of stagnant water increases. Compaction impairs the capability of the soil of being rooted and because of the impeded aeration reduces the physiological root activity, i.e. the supply of nutrients to the plant. The yield-reducing effect of soil compaction has been proved many times and may reach a considerable extent. In countries with an intensive plant production, the technogenic soil compaction has become the main problem of soil fertility and soil degradation.

Due to their specific properties, soils are subject to the risk of compaction in various degrees. Soils of a light texture (having a large proportion of sand) are in general scarcely subjected to this phenomenon. The capability of being compacted increases with the rising clay content of the soils. But this capability diminishes with increasing stability of the aggregates. The stability of the aggregates is dependent upon the kind of the forces holding the aggregate together or the kind of the cementing clay substance between the primary particles. The highest mechanical stability is exhibited by the aggregates of the fersiallitic and ferrallitic soils of the humid Tropics cemented by free iron and aluminium oxides. Therefore, these soils show a slight inclination to compaction. But an intensive mechanical action on these soils also leads to abrasion and a gradual destruction of aggregates. It is of particular importance, however, that the oxide-bonded aggregates of the fersiallitic and ferrallitic soils are water-stable and do not show any susceptibility to pressure at a high soil moisture. This distinguishes these soils from the clay soils with prevailing three-layer minerals. The aggregates held together primarily by cohesion of the clay particles become increasingly sensitive to pressure when subjected to moistening and formation of hydration water envelopes about the clay particles. When a critical moisture content is exceeded, these soils are exposed to a very high risk of compaction and vehicles are only allowed to travel on them when these soils are below the aforesaid moisture limit. Soils with clays capable of swelling (montmorillonite) are particularly endangered. When moistened, the aggregates frequently will already disintegrate under the action of the swelling pressure, and the distinctly formed hydration water envelopes form sliding planes which favour the displacement of the particles under compressive load. The already high natural density of the tropical verisols will be increased when worked in a moist condition, the bulk density increases from an average of 1.8 to 2.0 - 2.2 (with a density optimum of about 1.4 !).

When machines travel on soils which are in an excessively moist condition and thus compacted, then a favourable structure condition usually cannot be regained immediately by the subsequent cultivation operation. Mechanical tillage provides only artificial, more or less coarse fragments which are obtained by breaking the compacted soil mass. One speaks of a technogenic fragment structure. They frequently excel in a polarisation of the pore size spectrum. The total pore volume mainly covers ultra-macropores and micropores. The smaller macropores and mesopores which are of particular importance to rooting and water supply are pronouncedly reduced. The restoration of the soil to a good condition of the structure after technogenic compaction is possible the quicker and more perfect, the higher the humus content and the biological activity of the soil.

The soil compaction is not only a consequence of the travelling of machines on the soil surface. Phenomena of compaction are also caused by tillage by means of share ploughs, namely, in the form of the so-called plough-pan or crumb-basis compaction. The development of this compaction of the topsoil basis is favoured by the working depths remaining constant for periods of several years. In this way, a sharp boundary between loosened and compacted material is brought about at the boundary between plough horizon and subsoil. This boundary of compaction forms a barrier for the roots and the subsoil is scarcely accessible to the plants. This acentuates the disturbances in the water and nutrient supply in dry spells. Pronounced plough-pan compactions may considerably aggravate damage due to stagnant water in moist periods. As to the development of the plough-pan compaction, working the soil when in a state of a high water content particularly favours it.

III. 2.1.6.6. Impoverishment of nutrients

The problem of impoverishment of nutrients is closely related with the humus content of the soil. In general, two main sources of the required nutrients provided by the soil are available for the plant: The nutrient release by weathering the silicates originating from the rock and by the mineralisation of organic substance. The nitrogen required for plant growth exclusively originates from the organic substance and the microbial bonding of N. With increasing degree of leaching and weathering of the soils, the nutrient content of the mineral soil component decreases and the part played by the biological circulation of nutrients gains in importance to the nutrient supply for the plant. In the ferrallitic soils of the humid Tropics as the formations with the highest degree of leaching and weathering, the nutrient supply of the natural vegetation cover is mainly based on the continuous mineralisation of humus constituents. The increased mineralisation of the humus reserve associated with the clearing of the rain forest, while at the same time the supply of fresh organic substance is suddenly reduced, leads to a rapid impoverishment of nutrients in the soil. Consequently, the yields decrease quickly so that the cleared plot of land must be abandoned after a few years. This is the proper cause of the shifting cultivation traditional in the Tropics. The impoverishment of nutrients is accelerated when clearling by fire. In the savanna regions, the widely used pasture burning also contributes to the impoverishment of nutrients, especially nitrogen and sulphur. In view of the higher mineral nutrient reserves, the consequences are not so aggravating as on the ferrallitic soils of the fain forest.

The impoverishment of nutrients as a phenomenon of soil dagradation cannot be avoided in the Tropics. The consequences arising from this are of importance to the agricultural production and the feeding of the population as long as mineral fertilisers cannot be used. Basically, the impoverishment of nutrients can be compensated by mineral fertilisation. Practically, this gives rise to a number of difficulties which are associated with the unfavourable storage and transformation capacity for nutrients in soils of a high leaching and weathering degree. These problems can be solved, however, when using fertilisers possessing the desired properties and by the appropriate fertilising technologies.

III. 2.1.6.7. Petrification

Petrification is defined as the formation of zones of stony hardness within a soil profile. Thickness, density and hardness of these petrified zones vary within wide limits. Hardening may develop by the accumulation of crystallisation of quite different materials. Calcium carbonate, silicic acid and free oxides of iron and aluminium frequently are the substances of petrification. The respective petrified zones are called calcretes, silcretes, ferricretes.

The existence of a hardened zone in the soil profile naturally is of far-reaching importance to soil development, soil properties and plant growth in the site in question.In all cases where the hardened horizon developed from the absolute accumulation of the substance causing the hardening, the petrified zones also excel in a high density. It gravely impairs the water and air circulation and the rooting. The thickness of the soil layer on top of the petrified zone is of decisive importance to plant growth and workability of the soil. The agricultural use of the soil is impaired the less, the deeper the upper limit of the petrified zone is located in the soil.

The problem of petrification is associated with soil degradation in tow respects:

1. In regions with flat located petrification, the soil erosion

may have particularly aggravating consequences, irrespective of development and condition of the petrification, because the thin soil layer can be removed quickly and the landscape is fossilised. Growth of plants then is no longer possible.

2. As to both carbonate petrification in the aric regions and oxide petrification in humid climate, the view was held that they may develop within a short time due to measures of land-use in agriculture and forestry.

The increased hazard of landscape degradation in regions with flat located petrification is undisputed. In all cases where the loose soil layer on top of the petrification is less than 40 cm in thickness, arable farming should not take place and the soil should be protected by a permanent plant cover. If indicated, pasture farming should also be obviated.

The development of petrification due to measures of land-use should be of minor importance. As to both carbonate petrification and oxide petrification, the viewpoint is more and more accepted that their development is attributed to geochemical processes of early epochs of very long spaces of time. The majority of petrifications found in the Tropics presumably is fossil. Oxide accumulations in the soils and weathering covers of the humid Tropics, which have the capability of hardening when oxygen is admitted while water is lost at the same time (so-called soft laterite, according to Pullan, 1967) obviously occur by far not so often as has been supposed for decades until the recent past.

The anthropogenically induced petrification is possible but it is no serious problem of soil degradation. Of particular importance, however, is the exposure of already existing petrifications due to accelerated soil erosion.

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